SEWAGE WORKS JOURNAL

VOL. XI SEPTEMBER, 1939 No. 5

Special Articles

Experimental Studies of Industrial Wastes:

Digestion of Packinghouse Sludge—Knechtges
Digestion of Paper Pulp—Hill
Chemical Treatment of Textile Wastes—Porges

Experiences With Elutriation—McNamee

Colloids in Sewage—Rudolfs

Trends in Sewage Treatment—Hardenbergh

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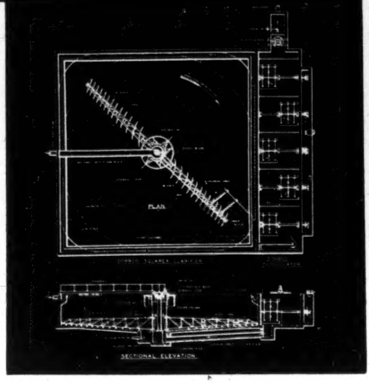

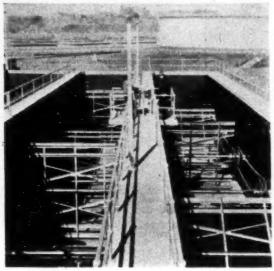
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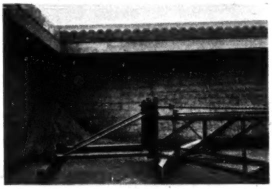
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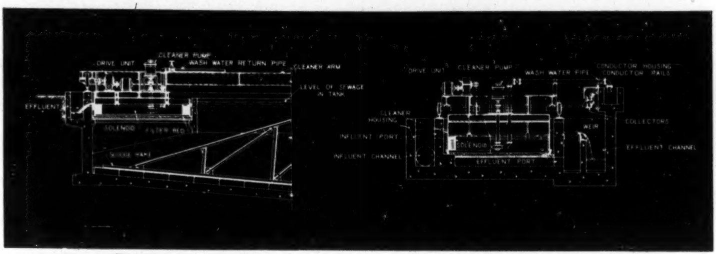
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LEFT: Upflow Filter in circular settling tank. **RIGHT:** Downflow Filter in separate structure.

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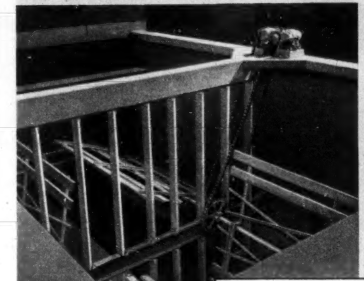

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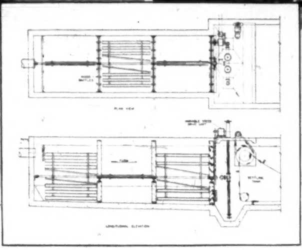

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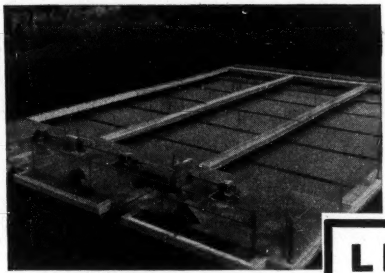

Link-Belt STRAIGHTLINE Collector. High efficiency, long life, low maintenance and positive removal of sludge make the STRAIGHTLINE Collector the preferred unit for removing sludge from rectangular settling tanks. This installation is at Janesville, Wis. Joseph Lustig, City Engineer.

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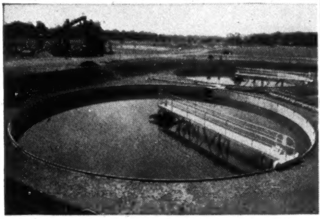

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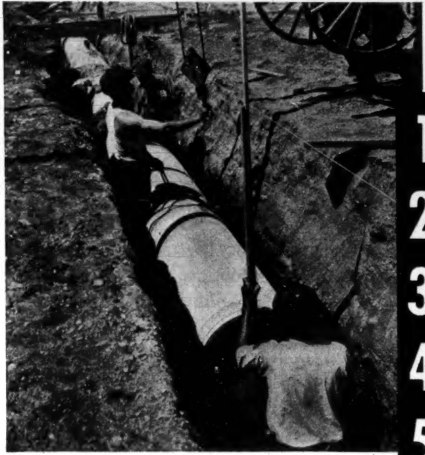

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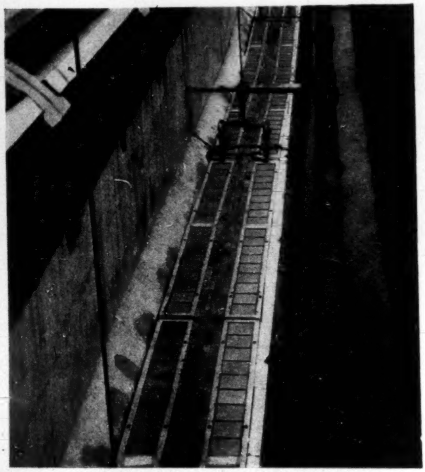

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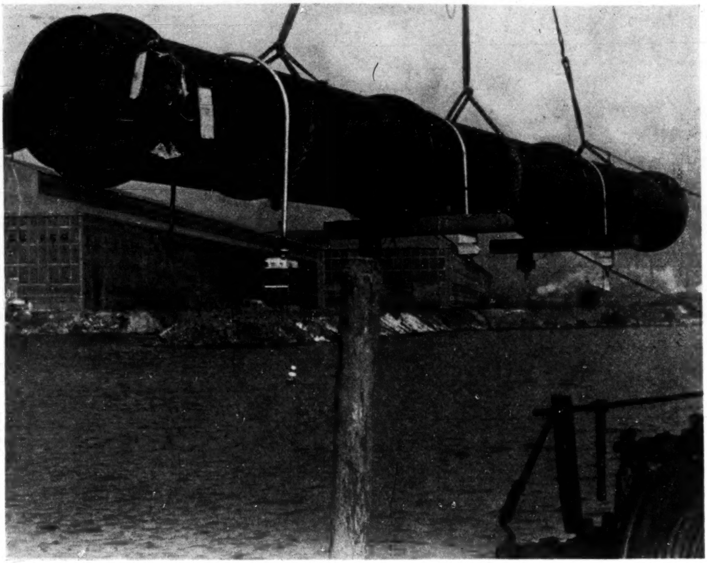

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Sewage Research

COLLOIDS IN SEWAGE AND SEWAGE TREATMENT *

I. OCCURRENCE AND ROLE. A CRITICAL REVIEW

By Willem Rudolfs and Harry W. Gehm

Chief, and Assistant, Dept. Water and Sewage Research, New Brunswick, N. J.

This discussion will be limited to an outline of the occurrence and rôle of the colloids involved in sewage and sewage treatment, without detailed explanation regarding the theories brought forth to explain their behavior. The latter will be treated in a separate discussion.

The colloids in sewage and those involved in treatment processes are of four general types: gels, sols, foams and emulsions. They consist of both organic and inorganic materials. In sewage itself we are most concerned with emulsions and sols. The dispersed matter invariably present, which cannot be settled out, has been referred to on numerous occasions as the colloidal fraction of sewage. In fresh sludges, digested sludges and supernatant liquor from digesters we have colloids of at least two types. The slimes on the stones of trickling filters, sand filters, colloiders and streams and the activated sludge floc are gels. The latter are mainly organic in nature. At times, however, inorganic colloids are involved. The presence of clays in suspension in sewage may constitute a sol and the hydrous floc formed in chemical treatment processes constitutes a gel of partial inorganic nature.

We are concerned not only with the existence of these colloids but, more important, the interplay between them and their behavior under different conditions. The sorption of sols by gels is one of the most important phenomena, as it is involved in the activated sludge process, trickling filters, sand filters and perhaps in chemical treatment and sludge conditioning. The dispersion medium is also of interest because the character of the dispersed matters and their reactions are dependent upon it. Another less frequent colloidal form met with in sewage work is the foam from digesters, aeration tanks and degreasing tanks.

Data available in the literature, together with some unpublished information obtained in our laboratories will be discussed in an effort to summarize our relatively limited knowledge of the complex materials dealt with in sewage treatment.

---

* Jour. Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Dept. Water and Sewage Research. Presented before the Water, Sewage and Sanitation Division of the American Chemical Society, April 5, 1939.

SEWAGE COLLOIDS

In practice the term colloidal material has been generally applied to the non-settleable fraction of sewage, particularly in this country. This is undoubtedly incorrect, but serves a useful purpose to indicate that the finely divided (true and pseudo-colloidal) materials are of importance. For several years English investigators have been busy studying the characteristics of this fraction of sewage matter. Recently Williams and Mills have done most of the work along this line but as far back as 1901 O'Shaughnessy (1) worked with the dispersed matter of sewage and observed many of its peculiarities.

METHODS OF MEASUREMENT

Methods for the determination of colloidal matter in sewage vary greatly and the quantities of colloids supposed to be present vary widely with the method employed. Among the methods used are those employed by Richter and Schmiedt, involving coagulation of the colloids with $FeCl_3$ and NH_4OH or KCNS, filtering and weighing; Rohland and Meysohn, adsorption of dyes; Mare and Sack, adsorption of colloids with $BaSO_4$ powder and determining the refraction of the water before and after treatment; Bach, adsorption with $BaSO_4$ and determining the oxygen consumed with $KMnO_4$; Nue, filtration of colloids through crude rubber and collodion; methods for ultrafiltration, electrodialyses, determinations of the nitrogen and carbon fractions, and several others. Depending upon the method employed the amounts of colloids supposedly present vary from 0.5 to 17 per cent of the total suspended solids. Some investigators, who include pseudo-colloidal substances, arrive at considerably higher percentages.

CLASSIFICATION

Various classifications of sewage solids have been made. The more frequently used grouping is that used by Mills (2, 3, 4, 5), namely: (1) settleable solids (material readily removed by sedimentation) (2) dispersed (not readily settled until it has been coagulated), and (3) soluble (not removable by sedimentation or flocculation). In making the separations necessary in the study of the dispersed fraction Mills employed the centrifuge, ultra-filters, dialysis and chemical coagulating agents. His interest centered on the organic matter present in the dispersed and dissolved portion of sewage, hence the analytical determinations used to demonstrate comparative quantities of material present were organic carbon and nitrogen.

Sewage.—Experiments on filtration of sewage through filters coarse enough to pass only particles of colloidal size, and through filters passing only soluble substances, show that little or none of the organic dispersed matter was of the true colloidal sol size, because the amount of organic carbon and nitrogen in both filtrates was the same in the case of numerous samples. Mills shows that both centrifuging over long periods and coagulation with small quantities of flocculating chemicals does not affect the quantity of organic matter in the ultra-filtrate, and since this filtrate exhibits no Tyndall cone effect, it is believed to contain only truly soluble matter. Short periods of centrifuging removed most of the fine suspended matter, while periods up to six hours removed a small additional amount. The average amount of organic carbon in eight samples after one hours centrifuging was 112 p.p.m., and after 6 hours 98 p.p.m., while the ultra-filtrate contained 93 p.p.m. The difference between the 6-hour centrifuged samples and the ultra-filtrate is but 5 p.p.m., so that the amount of matter unremovable by accelerated centrifuging is a very small part of the whole. This is illustrated by the following figures:

RAW SEWAGE

Minutes Centrifuging	Org. Carbon in Supn't. Liquor
0	458
4	206
8	221
16	197
60	193
Ultra-Filtrate	147

The difference between the carbon in the ultra-filtrate and the supernatant after 60 minutes is taken as the carbon present in colloidal suspension. In the case of this particular sewage, which is representative of the others tested, only 46 p.p.m. or 10 per cent of the carbon at a maximum was present in this form. As trials showed that 10 to 20 per cent of that remaining could be removed by further centrifuging, it is apparent that generally less than 10 per cent of the organic carbon in sewage is present in the true colloidal sol state. Especially since the assumption is made that a certain fraction obtained contains the colloidal material. This may be correct as far as these sizes are concerned. It does not necessarily follow that changes in organic carbon reflect accurately the variations in colloidal matter, but evidence has been given and will be discussed showing that in sewage the nitrogen is of less importance. When dealing with digesting solids the variations may be greater.

The fact that true colloidal material is present in small quantities is substantiated by observations made by us when turbidity, suspended solids, oxygen consumed and B.O.D. determinations are used as measures of the amount of material present in the various fractions of sewage. These observations lead us to divide sewage solids into four groups rather than three by dividing the dispersed fraction into two groups, namely; pseudo-colloidal sols and true colloidal sols. The pseudo-colloidal sols are considered as the material passing a filter which removes all solids which would settle in a normal period of sedimentation and be retained on a filter of about 0.2 microns pore size. The true colloidal sols are those which pass the 0.2 micron filter but are retained on an ultra-filter which will pass only material in true solution. From the figures below it is seen that when the oxygen consumed determination is used only 9 per cent of the total oxygen absorbing material is present in the form of particles of less than 3 microns diameter. This would tend to check closely the data of Mills. The total amount of dispersed mixture, as measured by the turbidity after removal of the settleable fraction, is made up of 75 per cent pseudo sols and 25 per cent of particles less than 3 microns in size. Since colloidal sols are less than 0.2 microns in diameter it is safe to assume that probably much less than 10 per cent of the total oxygen consuming matter in sewage is in the sol state.

FRACTION CLASSIFIED

Per cent of Total	Settleable Solids	Pseudo Sols	Susp. Matter Less Than 3 Microns	Dissolved Matter
Turbidity	—	75	25	—
Oxygen Cons.	44	16	9	31

Another characteristic of the bulk of the dispersed matter in sewage is the ease with which it is flocculated, as compared with true sols. Merely stirring or aeration for short periods of time leads to a marked coagulating action, which appears to take place principally by physical action despite the name (bio-flocculation) which the process carries.

Williams (6) in an attempt to determine the principal factors in sewage clarification, treated sewage with streams of bubbles of various gases and studied the coagulation of suspended matter. The determinations used were organic carbon and nitrogen in supernatant liquids and ultra-filtrates. He found that the same amount of coagulation was produced by air, nitrogen, hydrogen and oxygen over a 6-hour period. When the period was extended to 24 hours air and oxygen gave the best results. Coagulation could be produced by mechanical agitation out of contact with the air. Coagulation at zero and 10° C. was small but increased with the temperature. Good flocculation was obtained at 25°, 37° and 80° C. Rudolfs and Gehm (7) studied flocculation with paddles and compared it with aeration. Slow stirring of settled sewage reduced the turbidity in the supernatant liquid from 240 to 120 p.p.m. in 1.5 hours. Air at 0.24 cu. ft. per gal. produced equal flocculation as compared with paddle mixing over a ½-hour period. The removal of dispersed matter and B.O.D. when sewage was stirred in atmospheres of air, oxygen, nitrogen, carbon dioxide and ozone, and by aeration with the same gases (8) showed, under laboratory conditions, that over 40 per cent of the suspended solids could be removed by 30 minutes stirring, while turbidity removal amounted to about 25 per cent and B.O.D. over 30 per cent of the dispersed fraction. Longer treatment produced better results but not in direct proportion to the time required. Studying the removal of dispersed matter by paddling and settling in relation to the amount of dispersed matter originally present, Gehm (9) found that the amount removed was in direct proportion to the quantity originally present. Long periods of flocculation did not remove much of the 30 per cent of dispersed solids remaining after 5 hours agitation and settling. This 30 per cent remaining is close to the amount of turbidity which was found to pass through a 3 micron filter.

In determining the cause of the coagulant demand of sewage, it was found (10) that emulsions of soaps added to sewage and water responded to paddle and aeration treatment in a manner similar to sewage. Short intervals of paddling caused agglomerates to form and settle out, leaving the supernatant clarified to quite high degrees. As the sewage unquestionably contains soap emulsions it is probable that this agglomerating effect takes place when sewage is paddled or aerated. How much of the pseudo-sol fraction is generally composed of emulsions will be discussed later.

The effect of the dispersion medium on the quantity of sol and character of the dispersed matter has attracted the attention of investigators for years. The application of acids and bases to sewage for coagulation were employed in the first chemical treatment processes. Such treatment may amount to nothing but artificially altering the character of the dispersion medium. Upon this principle all processes involving changes in pH of sewages are based. Mills (11) determined the effect of various neutral salts added to the sewage on the dispersed material and found little effect up to 0.6 per cent sodium chloride and 0.14 per cent sodium sulfate concentration. Bonacci (12) found that by removing soluble substances by electro-dialysis coagulation of practically all the suspended matter took place. This treatment removed soluble inorganic salts and soluble organic compounds. Investigating in detail the effect of altering the pH of the dispersion medium on the coagulation of the dispersed material (13) it was found that the least amount of solids remained in suspension at about pH 3.0 to 4.0 and pH 9.0 to 10.0. It is evident that around the neutral point, which is the normal pH of sewage, dispersion is at a maximum.

Fresh Solids.—In the case of fresh solids which have not been allowed to decompose the various fractions of dispersed matter have not been thoroughly investigated. The fact that fresh solids are readily dewatered with comparatively small doses of coagulant which increase with partial digestion leads us to believe that the amount of colloidal matter is relatively low. There is further evidence in the fact that during digestion organic acids are formed, which rapidly disperse some of the constituents, especially those of a carbonaceous nature (Pedlow, 14), leading to an increase in the concentration of sols and finely divided substances which interfere with dewatering. The further acid decomposition progresses the more difficult filtration becomes. When the finely divided and colloidal substances are destroyed by bacterial action, dewatering becomes gradually easier with less coagulant requirements.

Examination of samples of supernatant liquor from fresh solids allowed to digest without seed for two months revealed that a concentration of finely dispersed matter was present, a large portion of which passed through a 0.2 micron filter. The material caught on the surface of the filter resembled a gel. It appears that under these conditions both sols and gels were present in the liquor in relatively large quantities. Any emulsions present in the original material are undoubtedly broken down as the fats are decomposed.

Ripe Sludge.—Comprehensive work on digested sludge has been done by Genter (15) (16) in connection with elutriation and vacuum filtration of sludge. By washing out some of the soluble and fine suspended solids from ripe sludge he found that dewatering could be accomplished with much less coagulant. He explained this phenomenon by pointing out a decrease in the amino-ammonia nitrogen content in the washed sludge liquor, claiming that such substances caused an increase in coagulant demand due to their adsorption on the surface of the larger particles, making it more difficult to change their surface charges and to release the adsorbed water.

This process is based on altering the dispersion medium around the gel particles. Genter holds that the sludge particles are emulsoid in character, because of the fact that they cannot be held long after the addition of a coagulant without redispersion of the floc, which is a typical property of such colloids. The observation that sludge should be dewatered as soon as possible after coagulant treatment has been substantiated almost everywhere. There is, however, a question as to whether the amino-ammonia nitrogen is the agent causing the higher coagulant requirement in conditioning the sludge. Several sets of experiments were conducted in an effort to answer this question. Ripe sludge was elutriated and the dispersed matter in the elutriate removed by filtration and taken off the paper by back washing with a small quantity of saline water. This material caught on the filter was added to a portion of the elutriated sludge and the amount of coagulant necessary to give equal dewatering determined for both samples as well as for the unelutriated sludge. The following figures show that when the small quantity of finely divided materials were added back to the sludge, without the soluble matter, the amount of ferric chloride needed increased:

Ripe Sludge	Elutriated 1 : 1	Elutriated Fines Returned
7.8%	4.6%	6.0%

Although it was impossible to remove all finely divided material from the filter, the amount recovered constituted an appreciable percentage of the total fines filtered out, so that more nearly the original quantity of chemical was required for equal dewatering when the fines were returned.

In another series of trials the elutration was made with lime water which liberated some of the ammonia and gave a clear supernatant on settling. The fines remained in the sludge rather than being washed out with the elutriate. In this case the dewatering of the three sludges was compared and the following percentages of ferric chloride were necessary:

Ripe Sludge	Elutriated 1 : 1 Water	Elutriated 1 : 1 Lime Water
7.2%	3.6%	5.5%

When the dispersed matter was retained in the sludge, more dewatering chemical was required.

A sample of ripe sludge containing 10 per cent solids was diluted with water and another with Seitz filtrate of the same sludge to half the original concentration. The Seitz filtrate contained the dissolved materials plus a small quantity of sol. If the amino-ammonia compounds are responsible for most of the coagulant demand it could be expected that the sludge with Seitz filtrate would require more coagulant. The results obtained showed that the amount of ferric chloride necessary to obtain good dewatering was the same.

The coagulant demand of ripe sludge was determined and the sludge allowed to digest until the supernatant was clear, indicating as has been shown by Pedlow that the finely divided material had been greatly reduced. The amino-ammonia nitrogen was slightly reduced and the sludge dewatered with less than 1 per cent ferric chloride.

These various experiments tend to show that the colloidal substances play an important rôle in the dewatering process despite the fact that their concentration is relatively low. It is also evident that the soluble matter does not determine the chemical requirement for dewatering. The experiments do not show that certain amino compounds may not exert an effect on the coagulant demand of sludge. Some of them may be absorbed by the sols and thus react with the coagulant. They do show, however, that definite suspensoids are present in ripe sludge which influence dewatering considerably. It should be remembered that in sludge dewatering considerable moisture remains in the sludge cake, which cannot be pressed out. This seems to indicate that the gels remain after the free water has been separated out.

Aerobic Processes and Colloiders.—Wilson (17) pointed out and demonstrated that activated sludge consisted of a gel. Its water absorptive characteristics and surface activities allow ready classification. All the aerobic biological treatment processes such as activated sludge, sprinkling filters, contact beds, colloiders, etc., are dependent upon the gels of biological origin which are formed either in the liquid or upon surfaces with which the liquid comes in contact. What is of interest here is the surface activity of these gels. The rapid clarification that takes place when activated sludge and sewage are mixed has been well demonstrated. Heukelekian (17) followed this phase with pure organic and inorganic sols and soluble ammonia compounds. Similar experiments with various pure substances added to trickling filters have been conducted at a number of places.

The importance of surface areas and surface contact was advanced as early as 1906 by Jones and Travis (19) as an explanation of the removal of dispersed material. They found that increased deposition occurred when glass rods were placed in sewage. They claimed that the introduction of air increased the contact of the particles with the surfaces thus increasing the amount of material removed from suspension and explained the action as being one of surface attraction (Hampton doctrine), minimizing the importance of the bacterial gel formed on the rods. Dunbar (20) advanced the absorption theory, which provided for accelerated transfer by adsorption of agglomerates of dispersed matter on the slime. Blitz and Krohnke (21) suggested the formation of an adsorption compound of the colloidal matter and the biological slimes. The adsorbed materials were held to be oxidized in the slime forming "ferments" or chemicals which promoted adsorption.

Recently Zobell (22) has emphasized the importance of surfaces for concentrating food materials for bacteria. On this basis he explains the well known observation of increased bacteria counts obtained from bottles of stream water left standing. The concentration of food material and formation of gels is closely related. Whitehead and O'Shaughnessy (23), Dienert (24), Butterfield (25), Zigerli (26) and others call attention to the necessity of having inert materials present to allow deposition of slime bodies of sufficient size for rapid absorption of dispersed sewage matter.

For the absorption of soluble matter various statements have been made. Theriault (27) claimed the adsorbent principle in activated sludge as a base exchange or bio-zeolitic substance.

Theories of adsorption of dispersed matter by neutralization of electrical charges have been advanced. Cavel (28) inferred that slimes were positively charged since they absorbed negative sols, such as congo red. Hence, he reasoned, sewage particles must be negative. Buswell (29) determined that the dispersed particles as well as the activated sludge particles were negatively charged, thus mutual attraction could not explain the absorption. Baly (30) and Lumb (31) avoided this barrier to the mutual attraction theory by assuming that dispersed particles will be absorbed by bacteria of stronger like charge as implied by the work of Dienert (24).

Foams are defined as dispersed systems of globular liquid films enclosing vapors and gases. These colloids are evident in foaming sludge from digesters and Imhoff tanks, on degreasing or skimming tanks, and at times on aeration tanks. Interest in them from the operation standpoint is in preventing their forming and breaking them if already formed.

Discussion

Various methods of measuring colloidal sols in sewage have been employed and on the basis of newer investigations it is found that the quantity of true sol is low. On the basis of total organic carbon domestic sewage contains less than ten per cent in the sol state. The non-settleable material amounts to nearly one-third of the organic carbon content and contains other forms of colloids such as emulsions. That emulsions are present is evident from the fact that they are present in soapy water, much of which reaches the sewers, and that sewage dispersions on agitation or aeration form settleable agglomerates.

The importance of the sols is not yet fully established. They may play a part in treatment processes, because they are more difficult to remove by present methods of treatment than other suspended matter. However, when substances responsible for their dispersion are removed from the liquor they appear of no practical importance.

Fresh solids on decomposition rapidly become rich in colloidal matter of various types. The sols increase as the sludge decomposes, making filtration more difficult. The quantities involved have not been thoroughly investigated.

Ripe sludge contains sols and gels and emulsions. The importance of the sols is shown by the fact that their inclusion results in the necessity of using additional coagulant for dewatering. The dispersion medium may be of importance in the dewatering process as materials in solution might become adsorbed upon the particles. It appears, however, that the dispersed matter is the material mainly involved in determining the dewatering characteristics of a sludge.

Work pertaining to the dispersion medium in connection with sewage indicates that the effect of neutral salts is little, but that the agglomeration of some of the particles is controlled by the pH values of the liquor. As sewage is rarely completely clarified by acid or alkali additions it is probable that all but the true sols are coagulated. This applies also to flocculation by stirring, because the same amount of dispersed matter of a size smaller than 3 microns remains after long periods of stirring.

Bacterial jellies, such as activated sludge, various filter and colloider slimes, appear to be true gels.

In general, the physical or colloidal theories have indicated the adsorption of dispersed materials, but a need for a clarification of the mechanism in sewage treatment and more detail as to its operation still exists. The adsorption of soluble material on slime surfaces is still devoid of a good, complete explanation. Reliable estimations of the quantities of colloids are scarce.

In an attempt to classify the colloids present in sewage, sludges and slimes, the following scheme is tentatively set up:

Sewage—emulsions, sols
Fresh solids—gels, emulsions, sols
Ripe sludge—gels, emulsions, sols, foams
Skimmings—emulsions, foams, sols, gels
Activated sludge and other slimes—gels
Supernatant digester liquor—sols, emulsions, foams

This grouping is based on the present inadequate knowledge of the subject and may be changed or rearranged when more information becomes available. No attempt has been made in the present classification to indicate the amounts of the various colloids, because several estimates found in the literature are based upon incomplete information, inadequate technic for determination, or assumptions which cannot be substantiated. Further investigation of these materials cannot fail to bring improvement in existing treatment processes, better understanding of the materials involved, concrete knowledge of the reactions taking place and the introduction of new methods of treatment.

SUMMARY

A critical review of the literature on colloids in sewage and sewage treatment indicates that various methods of measurements produce widely varying results. The sewage solids are classified as settleable, dispersed, pseudo- and true colloidal sols, and soluble solids. The amounts of true colloidal sols are probably less than ten per cent of the total suspended solids. The amounts of colloids in fresh solids are relatively low; they increase during digestion and then decrease as digestion approaches completion. The colloids appear to be more important in sludge dewatering than dissolved amino-ammonia nitrogen. Bacterial jellies are most important in aerobic processes and streams. A tentative scheme for classification of colloids in sewage, sludges and slimes is given. Information on the amounts of various colloids is needed to improve various treatment processes and develop new methods.

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CHEMICAL COAGULATION OF SEWAGE *

XI. EFFECT OF SOLUBLE MATTER ON COAGULATION

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It is of considerable theoretical and practical interest to know the specific causes of chemical requirements in the coagulation of sewage and the reasons for the variations in coagulant demand. In a previous paper (1) it has been shown that neither settleable nor the coarser non-settleable solids present in sewage were responsible for the coagulant demand. The more finely dispersed and the soluble fractions were next investigated.

The more finely dispersed portions of the non-settleable solids refers to the particles that will pass through a fine paper filter but not through a Seitz filter. The particle size of material passing a fine paper and not the Seitz is in the range of 0.2 to 5.0 microns in diameter. The fraction which is referred to for practical purposes as the soluble fraction contains dissolved salts and organic matter and in addition particles of true colloidal sol size (under 0.2 microns). About 35 per cent of the solids found here are volatile and the carbon-nitrogen ratio of the organic matter is about 1:3. It was previously shown (2) that this fraction accounts for approximately one-third of the B.O.D. of domestic sewage.

Methods and Procedure

Coagulant demand tests were run as described previously in this series of articles (3). All other analyses were made according to Standard Methods of Water Analysis, except where otherwise stated in the text. Where paper filtration was involved Whatman No. 42 paper was used. In all Seitz filtrations E.K. filter mats were employed. These give a crystal clear filtrate at a sufficiently rapid rate to obtain a large amount of filtrate in a short time.

To determine whether the finely dispersed matter or the Seitz filtrate of sewage was responsible for the coagulant demand, the following experiment was made. Samples of sewage used were catch samples of strong domestic sewage. No sample was used which contained more than one p.p.m. of H_2S, because H_2S is effective in increasing the ferric iron demand.

Liter samples of sewage were treated with increasing dosages of ferric chloride to determine the amount necessary for complete clarification. Three 3-liter aliquots of this sewage were taken. One was diluted with one liter of distilled water, the second with three and the third with nine liters, so that the mixtures contained 75, 50 and 25 per cent sewage, respectively. The quantity of ferric chloride necessary to clarify each dilution was then determined. The above procedure was twice repeated with the same sample, using first paper filtrate and then Seitz filtrate of the same sewage instead of distilled water as diluent, and the ferric chloride demand of every dilution determined.

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Results

(*A*) *Fraction Responsible for Demand.*—The results of the above experiment illustrated in Table I demonstrate that when sewage was diluted with distilled water, the amount of chemical necessary for coagulation was in direct proportion to the amount of sewage present in the dilution. The presence of added water did not affect the dosage of chemical necessary to clarify a given volume of sewage. When either paper or Seitz filtrates of the sewage were used for dilution the same amount of coagulant was required for every dilution as was necessary when the entire volume was made up of raw sewage. The filtrates absorbed as much coagulant as the raw sewage. Since the results with the Seitz and paper filtrates were practically identical it is evident that little if any absorption of coagulant is caused by the finer non-settleable solids in the paper filtrate. The results indicate that the fraction containing only the soluble matter and the true colloidal sol influences the coagulant demand.

Table I.—*Effect of Fine Suspended Solids and Soluble Sewage Substances on Coagulant Demand*

Sample 1	P.p.m. Ferric Chloride as Iron			
Per cent of Sewage in Dilution	100	75	50	25
Distilled Water	30	22.5	15	7.5
Paper Filtrate	—	30	30	30
Seitz Filtrate	—	30	30	30
Sample 2	100	75	50	25
Distilled Water	20	15	10	5
Paper Filtrate	—	20	20	20
Seitz Filtrate	—	20	20	20
Sample 3	100	75	50	25
Distilled Water	25	18.8	12.5	6.3
Paper Filtrate	—	25	25	25
Seitz Filtrate	—	25	25	25

The next step was to determine if the organic or inorganic constituents were involved. Separation of the two was attempted by electro-dialysis without success, because both types of material diffused rapidly through the membrane and chemical changes occurred in the dissolved material, altering its character. The inorganic matter was finally segregated by evaporating 5 liters of Seitz filtrate to dryness and ashing the resulting residue at low temperature to burn off the organic matter, leaving the inorganic residue. Although some changes occurred in the inorganic matter on ashing it remained essentially the same. The ash of this filtrate was added to a five-liter sample of the same sewage from which it was derived and the coagulant demand determined on this sample and on one to which no ash was added. The same procedure was repeated with three other sewages.

Inspection of Table II will show that no rise in the demand was evident when the ash was present in the three samples used. It appears doubtful that in the absence of H_2S the inorganic soluble fraction is a major factor in determining the coagulant demand under normal conditions.

TABLE II.—*Effect of Ash of Seitz Filtrate on Coagulant Demand of Sewage*

Sample	$FeCl_3$ as Fe	Turbidity Remaining	
		Sewage	Sewage and Seitz Filtrate Ash
	P.p.m.	P.p.m.	P.p.m.
1	10.0	23	18
2	17.5	34	43
3	32.5	28	28

Steel and Zeller (4) demonstrated that the addition of potassium permanganate to sewage lowered the dosage of coagulant necessary for clarification. We surmised that either the permanganate oxidized some of the soluble organic matter or the manganese ion aided coagulation. In order to determine which was the case 0, 5, 10 and 15 p.p.m. of potassium permanganate were added to liter samples of Seitz filtrate of a sewage. A contact time of two hours was allowed for the chemical to react. An equal volume of the same sewage was added to the filtrate and the coagulant demand again determined. The results of this experiment are given in Table III. A definite reduction in coagulant demand resulted when the Seitz filtrate had been treated with potassium permanganate. As none of this compound remained in solution as such after contact with the Seitz filtrate it appears that

TABLE III.—*Effect of Treatment of Seitz Filtrate with $KMnO_4$ on Coagulant Demand of Sewage*
Sewage Plus Seitz Filtrate

$KMnO_4$ as Oxygen	$FeCl_3$ as Fe for Clarification
P.p.m.	P.p.m.
0	31
10	28
20	20

the reduction in coagulant demand was due to oxidation of some of the soluble matter rather than coagulation effected by the manganese ion.

The organic matter in the Seitz filtrate appeared to determine the coagulant dosage; a possible relation may exist between the gross quantity of such material and the coagulant demand. Twenty-four different samples of sewage were treated to determine the coagulant demand and the organic matter in the Seitz filtrate of each measured by the 5-day B.O.D. using seeded dilution water. In Table IV the results of this series are presented. No correlation could be found between the chemical dosage and the 5-day B.O.D. of the soluble matter.

TABLE IV.—*Comparison of Iron Demand and B.O.D. of Seitz Filtrates of Sewages*

Coagulant Demand $FeCl_3$ as Fe	B.O.D. Seitz Filtrate	Coagulant Demand $FeCl_3$ as Fe	B.O.D. Seitz Filtrate
P.p.m.	P.p.m.	P.p.m.	P.p.m.
10	54	35	79
15	45	40	70
20	20	40	67
20	36	40	50
25	73	45	23
25	55	45	56
25	44	45	23
30	55	55	50
30	73	55	29
35	35	60	35
35	59	60	80
35	75	60	51

Realizing the variations commonly found in the 5-day B.O.D. determinations of various sewages, a series was run using organic carbon as a measure of the organic matter in the Seitz filtrate. Twelve sewages were used and treated in the same manner as in the previous series except that the determination of organic carbon surplanted the

TABLE V.—*Comparison of Coagulant Demand and Organic Carbon in Seitz Filtrate of Sewages*

Coagulant Demand $FeCl_3$ as Iron	Organic Carbon in Seitz Filtrate
P.p.m.	P.p.m.
5	31
10	20
12.5	35
15	23
20	18
30	18
15	25
20	27
22.5	19
30	36
40	28
40	21

B.O.D. Here again no correlation was found to exist as evidenced by the results given in Table V. It appears, therefore, that the gross amount of carbonaceous organic matter present in the Seitz filtrate is not an index of the coagulant demand.

From a survey in which samples were taken every hour from a source of purely domestic sewage and coagulation tests and various analyses made on them, some interesting relationships were noted. The first was the differences in the degree of clarification effected by increasing doses of chemical on each sample. Different type clarification curves were observed for samples taken at different hours of the day. Samples taken early in the morning as people were rising showed a tendency to decreased clarification upon addition of small doses of chemical or at least little improvement up to the point where the demand dosage was added. Other samples of sewage clarified slightly with partial dosage of chemical but required a complete demand dosage to yield appreciable results. Some samples clarified progressively with increased dosage, while others clarified to an appreciable degree on addition of a small amount of coagulant, but required much more chemical to complete clarification. Examples of these types of response to coagulant addition are given in Fig. 1. The time the sample was taken is noted in each case.

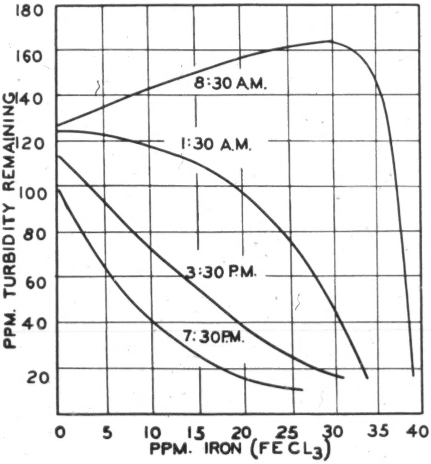

FIG. 1.—Coagulant response of domestic sewage sampled at different times of day.

Another observation made was the close correlation between the NH_3–N content of the sewage samples and the chemical demand. This correlation was so close that it was thought advisable to repeat the work on other sewage sources. The results for four sewages are illustrated in Figs. 2 and 3. It will be observed that the relationship held for the other sewages but to a less degree for the stale Plainfield sewage, containing large quantities of ammonia.

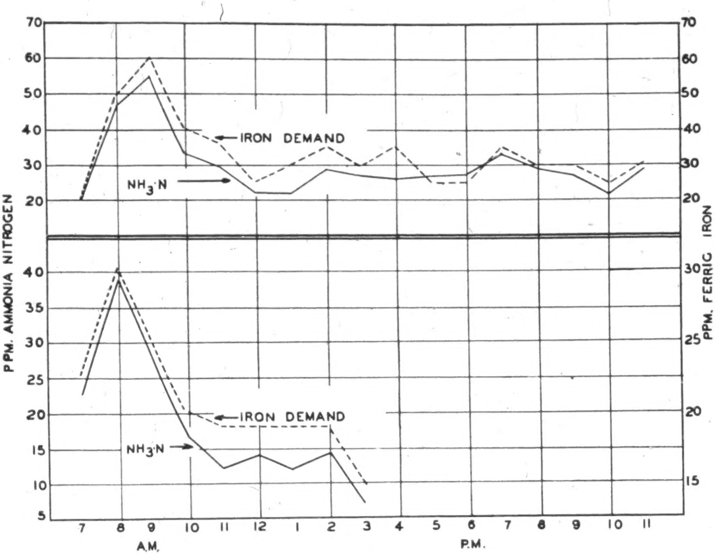

FIG. 2.—Relationship of ferric chloride demand and ammonia nitrogen content of Highland Park sewage.

Since the quantities of ammonia nitrogen in parts per million correlated so well with the iron demand, the question arose as to whether the ammonia compounds present in sewage were responsible for the demand.

(*B*) *Effect of Pure Compounds.*—The effect of the addition and removal of ammonia was determined. A sewage containing 20 p.p.m. of ammonia nitrogen and a coagulant demand of 20 p.p.m. of iron was used. To three equal portions of this sewage ammonium carbonate was added raising the ammonia nitrogen contents to 25, 30 and 40 p.p.m., respectively; to other aliquots ammonium chloride was added, raising the ammonia nitrogen to 28 and 120 p.p.m. For two other portions zeolite was used to lower the ammonia content to 15 and 5 p.p.m. respectively. The amount of iron salt necessary to clarify these treated samples was measured. The results presented in Table VI show that the addition of these ammonium salts or the removal of ammonia from sewage did not change the coagulant demand. The only case in which any reduction was noted was in the sample treated with an excessive quantity of ammonium chloride. The demand was not reduced more than would be expected with the addition of any neutral monovalent salt.

In connection with these results it was noted that early morning sewages, sometimes not exceptionally strong when measured by other indices of strength, showed a high ammonia content and required a

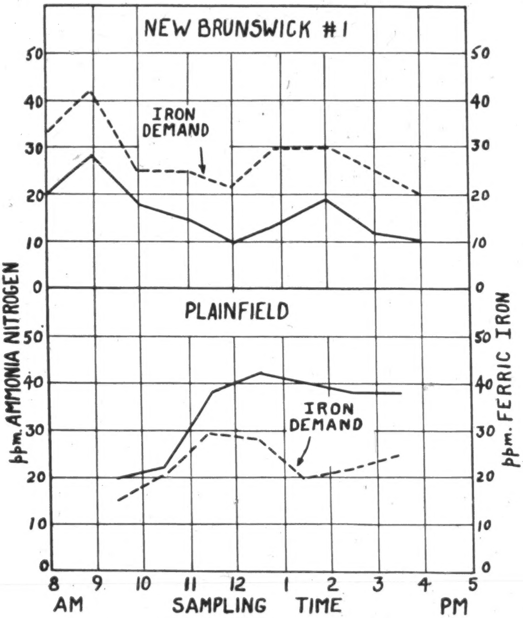

FIG. 3.—Relationship of ferric chloride demand and ammonia nitrogen content of two other domestic sewages.

TABLE VI.—*Effect of Addition and Removal of Ammonia on the Coagulant Demand*

	NH_3-N	$FeCl_3$ as Iron
	P.p.m.	P.p.m.
Sewage Untreated	20	20
Sewage	25	20
+		
Ammonium Carbonate	30	20
	40	20
Sewage	28	20
+		
Ammonium Chloride	120	15
Sewage	15	30
Zeolite	4	30
Treated		

large amount of ferric chloride for complete clarification. This high ammonia content is undoubtedly due to urine. It seemed reasonable to suspect that urine and its various constituents were responsible for at least a part of the coagulant demand of sewage.

Addition of increasing quantities of urine to sewage and the effect on clarification with a constant coagulant dosage as determined by measuring the turbidity remaining after treatment is shown in Table VII.

Table VII.—*Effect of Urine on the Coagulant Demand*

Sample No. 1 20 P.p.m. Fe Used				
Weak Urine ml. per l. Sewage	0	0.5	1.5	5
Turbidity remaining	24	24	38	116
Sample No. 2 30 P.p.m. Fe Used				
Strong Urine ml. per l. Sewage	0	0.5	1.5	5
Turbidity remaining	10	35	120	145

The effect of adding urine was indicated by a definite decrease in the degree of clarification obtained from a given coagulant addition. It appears that the more urine added the poorer the clarification. In order to check this observation and to determine if the amount of urine present normally in sewage was sufficient to affect the demand for chemical, the following tests were made.

Allowing for a daily domestic sewage flow of 300 liters (about 80 gallons) per person per day and an excretion of 1.5 liters of urine per person per day the concentration, if distributed equally over the day, would be 5 ml. of urine per liter of sewage. This amount was added to three samples of sewage of known chemical demand. The samples were then treated to determine the increase in demand due to the urine.

The data presented in Table VIII demonstrates the increased coagulant demand, amounting in each sewage to 10 p.p.m. iron, caused by 5 ml. of urine.

In an effort to determine which substances present in urine were responsible for the increase in demand, known constituents of urine were added in pure form and their effect on the iron demand determined. Urea, uric acid, creatinine, hippuric acid and the ash of urine were used. The amounts applied varied from ten to 100 p.p.m. Seven amino acids were also tried. These were, namely, cystein, arginine, alinine, histidine, phenylalinine, asparagine, and glutamic acid. A phosphoprotein was also used. These substances were added in quantities varying from 10 to 100 p.p.m.

The results obtained show that none of these compounds raised the coagulant demand. Even as much as 100 p.p.m. had no effect.

TABLE VIII.—*Increase in Coagulant Demand Due to Added Urine*

Sample	P.p.m. FeCl$_3$ as Iron	
	Required for Clarification of Sewage Alone	Required for Clarification of Sewage + 5 ml. Urine
	P.p.m.	P.p.m.
Plainfield	25	35
Highland Park	15	25
Morristown	8	18
Average	16	26
Increase Due to Urine		10

Some compounds essentially carbonaceous in character were next added to sewage to determine if such compounds, or substances similar to them, present in sewage, had an effect on the demand. Fatty acids, namely, formic, acetic, propionic, butyric and valeric, were used in dosages of 10, 20, and 50 p.p.m. The hydroxy acids, lactic, citric and tartaric, were tried in like amounts. Sodium bicarbonate was added in concentrations of 25, 50, 75 and 100 p.p.m.

None of the above compounds appeared to influence the coagulant demand in a positive manner. Some slight decreases in demand were noticeable when large dosages (over 50 p.p.m.) of these chemicals were added but in no case was it increased to a determinable extent.

(*C*) *Effect of Coagulant on B.O.D.*—In earlier published results (5) it was shown that the B.O.D. of the whole sewage is reduced by the addition of ferric chloride. It appears that the lowering of the B.O.D. is due to the combination of the iron with organic compounds to form products which are not readily assimilated by bacteria. To show this effect Fig. 4 is presented.

How much, if any, of the Seitz filtrate of sewage alone is rendered unavailable to the organisms is not known. A knowledge of this, in view of the fact that these substances are active in determining the coagulant demand, would give us additional confirmation of former observations and a possible insight into the mechanism involved. Therefore, the following experiment was made:

Aliquots of seven different strong settled domestic sewages were treated in the usual manner with graduated dosages of FeCl$_3$. Immediately after flocculation (before any sedimentation took place) a portion of each was dispersed, care being taken to get a representative sample, and the 5-day B.O.D. determined. The original samples were then allowed to settle and the supernatant sampled for the determination of suspended solids. Another sample of the same supernatant was taken and Seitz filtered and 5-day B.O.D. determinations were made on the filtrates. By subtracting the B.O.D. of the filtrate from the B.O.D. of the mixed liquor, the B.O.D. of the material in suspension was calculated, the Seitz filtrate being considered as containing the soluble fraction.

The results obtained with the seven sewages employed were averaged, as all results showed the same trends. In Fig. 5 the B.O.D. values of the suspended matter are plotted against the coagulant dosage. The suspended solids in the supernatant are also shown in curve form. It appears that the coagulant combined but little with the suspended matter until clarification was complete. When the demand dosage was added the B.O.D. of the suspended matter was reduced less than 10 per cent. Addition of $FeCl_3$ in quantities greater than the demand reduced the B.O.D. of the suspended matter materially; doubling the iron demand reduced the B.O.D. almost 50 per cent. In Fig. 6 the effect of the coagulant on the soluble B.O.D. in terms of the $FeCl_3$

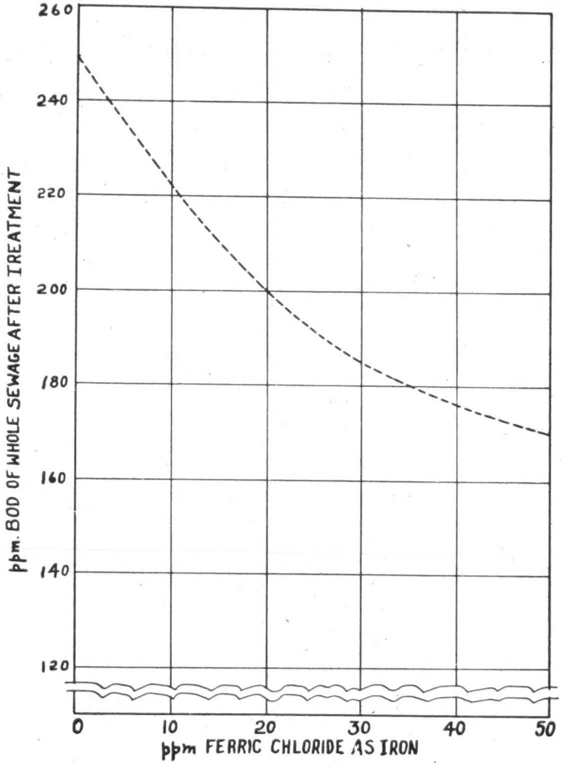

FIG. 4.—Effect of ferric chloride on the B.O.D. of sewage.

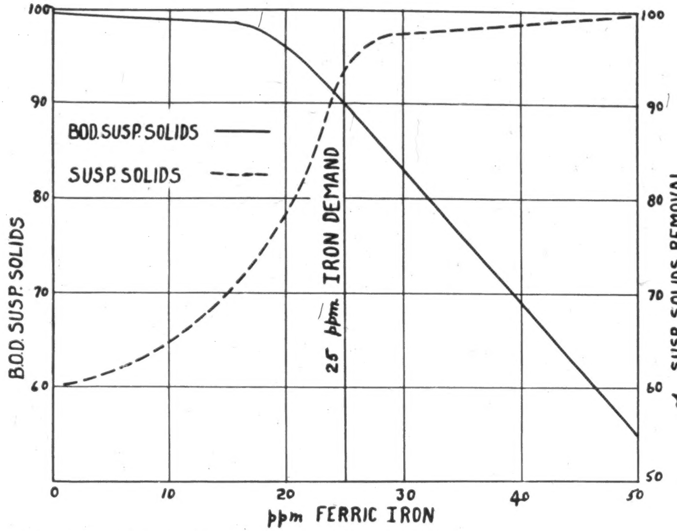

FIG. 5.—Effect of ferric chloride on the suspended B.O.D. compared to degree of clarification obtained.

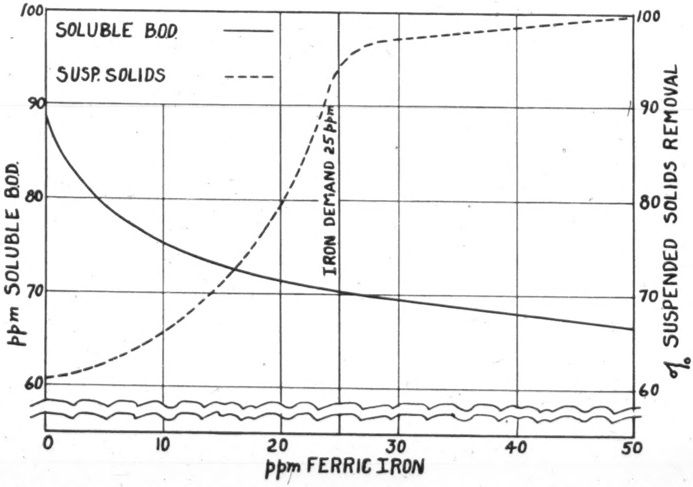

FIG. 6.—Effect of ferric chloride on the soluble B.O.D. compared to degree of clarification obtained.

dosage is compared with the curve for clarification. Here the greatest reduction took place before clarification was complete while dosages in excess of the demand caused little reduction. The soluble B.O.D. was reduced over 22 per cent by the demand dosage while twice that dosage caused only an additional 3 per cent reduction.

Discussion

The first experiments presented in this paper showed that the substances present in sewage which pass through a Seitz filter are responsible for the coagulant demand. In the practical sense this fraction consists of the soluble matter, but it may also contain some colloidal sol of very small particle size. It appears that the coagulant is absorbed by organic materials present in this fraction. This may take place simultaneously with clarification in the case of some sewages, while in others this material must be first satisfied before appreciable clarification will take place. In some cases the liquor becomes more turbid due to dispersed iron compounds forming when partial treatment is applied. This latter is particularly the case with morning sewages containing more urine than those collected later in the day as urine has the ability to increase the coagulant demand.

The concentration of soluble substances interferring with flocculation may be the reason for the various types of clarification curves obtained throughout the day. There is no doubt that urine accounts for a large part of the demand, when we consider that additions in amount equal to the calculated average concentration raised the demand 10 p.p.m. of iron. The close correlation of the ammonia nitrogen, whose main source is urine, and the coagulant demand is additional evidence that the more urine present the higher the demand.

This does not mean that the coagulant merely alters substances which interfere with a natural tendency on the part of the particles to coalesce. Some action on the suspended matter takes place, as a tough floc is formed. When the soluble matter (6) is removed by dialysis the particles do coalesce but the floc formed is fragile and easily redispersed. However, if the interfering substances were not present, coagulation with the formation of a stable floc would probably take place on the addition of very little coagulant. The fact that the B.O.D. of the suspended matter was reduced 10 per cent before demand dosage was reached indicates that a combination did occur.

The failure of any of the pure urine substances used to react in the same manner as urine is due either to the fact that it is the transitory products of decomposition that are active or that certain true sols are present which are responsible for this absorption. Experiments have shown that none of the type organic soluble compounds in the pure state, which may be found in sewage, influence the demand.

The means by which the soluble matter interferes with coagulation was shown by the B.O.D. studies, in which the effect of the coagulant upon the dissolved and suspended matter was determined. It was found that a combination of the iron with the soluble organic matter took place up to the point where clarification was complete. The fact that the organic matter is no longer available to the organisms is considered evidence that a combination has taken place. Some action on the suspended matter is also evidenced up to the point where the demand is reached but the greatest effect on this fraction comes when dosages in excess are applied.

The action of the ferric salt on the organic matter may be one of base exchange. That the organic matter of the soil acts in this manner is a known fact. Certainly the iron does not act as a toxin. This is evidenced by the B.O.D. rate curves presented in Fig. 7. The sample treated with excess of chlorine is a typical toxic rate curve, in which the oxidation is definitely delayed. In the case of the coagulant-treated sewage the rate is very much the same as that of the untreated sewage, the only difference being that the actual values are depressed, denoting that less material was available for oxidation through the duration of the process of oxidation. It is known that soaps will combine with the coagulant to form iron soaps. This action may take place to some extent when sewage is coagulated, but probably becomes more extensive when an excess of coagulant is applied. The

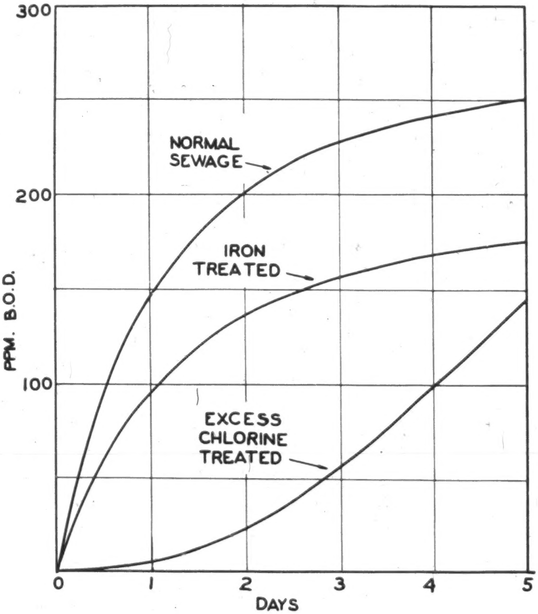

Fig. 7.—B.O.D. rates of ferric chloride and excess chloride treated sewage.

matter of iron exchange and the effect of decomposition products will be discussed further in respect to coagulation, together with other possible reactions and the theories involved, in following papers.

CONCLUSIONS

Coagulation experiments with different types of sewages and groups of substances present in the sewages divided physically in various fractions, together with additions of pure chemicals representing possible sewage constituents have shown that:

1. The soluble or the colloidal sol, and not the coarse dispersed material, is mainly responsible for the coagulant demand.
2. The amount of dispersed matter is no index of the coagulant requirements of a sewage.
3. The amount of dispersed matter removed by a given amount of coagulant varies in the same sewage when samples are taken at different times of the day. Thus the dispersate is of greater importance than the dispersed matter in determining coagulant dosages.
4. Organic rather than inorganic matter is responsible for the demand. However, no correlation between the gross amount of organic matter in the Seitz filtrate and the coagulant demand is evident.
5. A close correlation of the ammonia nitrogen content of sewage and the coagulant demand exists.
6. Ammonia itself plays no part but appears to be an index of the quantity of urine present.
7. Urine contains substances which absorb coagulant or interfere with the action of the coagulant.
8. Pure urine constituents and other organic substances found in sewage have no effect on the demand.
9. The demand is possibly due to transition products present in decomposing urine, or formed by combination of urine compounds with other materials found in sewage. It is also possible that colloidal sols present in urine may be responsible for its activity.

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CARBON AND NITROGEN TRANSFORMATIONS IN THE PURIFICATION OF SEWAGE BY THE ACTIVATED SLUDGE PROCESS*

II. MORPHOLOGICAL AND BIOCHEMICAL STUDIES OF ZOOGLEAL ORGANISMS

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Zoogleal organisms were first isolated from activated sludge by Butterfield (2) who described some of the morphological characteristics and methods of culturing of the organisms. Later, purification and oxidation rates brought about by activated sludge built up from the zoogleal organisms were reported by the investigators of the Stream Pollution Laboratories at Cincinnati of the U. S. Public Health Service (3) (4).

By introducing small quantities of clarifying organisms into sterile sewage, Heukelekian and Schulhof (5) obtained a slow clarification. The organic carbon values of the sludge ranged from 2.2 to 19.0 p.p.m., which would be equivalent to 5 to 40 p.p.m. of suspended sludge solids.

Carbon and nitrogen transformations brought about by a natural activated sludge were reported in the first article of this series (1). The method of approach outlined in that article was found helpful in interpreting some of the fundamental changes taking place in the purification of sewage by activated sludge formed from pure cultures of zoogleal organisms. These results will be presented in a subsequent paper. The present paper concerns itself chiefly with the morphological characteristics and biochemical reactions of the zoogleal organisms.

An attempt is made to answer the following questions:

(1) Does activated sludge floc contain one species of zoogleal organisms or are different species prevalent?

(2) How does the behavior of the organism change under various environmental conditions?

(3) What are the biochemical reactions brought about by the zoogleal organisms?

(4) Does the pure culture sludge built up from zoogleal organisms change its settling characteristics when the carbon-nitrogen ratio is changed by feeding a carbohydrate rich medium?

(5) What is the normal carbon-nitrogen ratio of a pure culture zoogleal sludge?

Experimental

Fifteen different activated sludges were obtained from various sewage plants. These natural sludges varied, some were bulky, and others settled rapidly. Isolation of the zoogleal bacteria from these sludges was based on the technique outlined by Butterfield (2). The method of isolation resembled one successfully employed for the isolation of plankton. Effort was made to purify the clumps of zooglea before planting in liquid media. Zoogleal clumps were teased from the activated sludge clumps with a sterile capillary pipette, transferred to a tube of sterile distilled water and centrifuged for 30 seconds at 750 r.p.m. The supernatant water was poured off, and the zoogleal floc transferred with a sterile capillary pipette to another tube of distilled water. This process was repeated approximately twelve times. The final tube of distilled water containing the zoogleal clump was shaken violently, and this suspension was implanted in serial dilutions in nutrient broth, the first tube of nutrient broth receiving the zoogleal floc. Incubation at 32° C. for 7 days showed slow development of zoogleal masses in dilutions up to 1/10,000. Plantings from the highest dilution showing growth were again made into nutrient broth, in serial dilutions as before. This process was repeated several times. The cultures of zoogleal bacteria obtained in this manner were next plated on nutrient agar. Although very few colonies of the zoogleal organism developed in the agar medium, there were enough sub-microscopic zoogleal colonies present in the agar after 7 days incubation to make isolation possible. Plantings were made into nutrient broth, and cultures developing upon incubation were considered pure. Morphological and cultural characteristics of the bacteria thus isolated were determined according to Standard Methods (6). Direct microscopic examinations of the natural activated sludges were also conducted, by means of Gram-staining.

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* Journal Series Paper, New Jersey Agricultural Experiment Station, New Brunswick, N. J., Dept. Water and Sewage Research.

Results

The fifteen natural activated sludges were washed several times with distilled water prior to microscopic examination, centrifuged, and the supernatant liquid discarded. This procedure was used to remove, as far as possible, extraneous bacteria present in the liquid phase, in order to observe the microscopic appearance of the sludge organisms themselves. A smear of activated sludge was made on a glass slide, and the film was dried, heat-fixed and Gram-stained. Microscopic study showed that the sludge flocs stained too heavily to permit clear observation. Accordingly, a drop of sludge was placed on a glass slide and ground thoroughly by means of a cover slip. In this manner, the larger microscopic forms present in the sludge such as protozoa, rotifers and nematodes were disintegrated and the bacteria making up the sludge floc proper were dispersed. Drying of this film, followed by heat fixation, Gram-staining and microscopic observation, showed, in every one of the fifteen different sludges, great predominance of Gram-negative rods, the length of which varied from 1.5 to 3.5 μ and the width from 1 to 2 μ. Very few Gram-positive bacteria were present in the sludges and in several cases they were entirely lacking.

The zoogleal bacteria of each of twelve different sludges were isolated according to the aforementioned method and studied separately in pure culture. The characteristics of these organisms are described in Table I. The most important observation made in this study was that, morphologically and culturally, the zoogleal organisms making up the different natural activated sludges appeared sufficiently alike to be classed either as one species or as one genus and that these organisms were not distinguishable from the zoogleal bacterium described by Butterfield.

TABLE I.—*Characteristics of Zooglea ramigera Cultures Isolated from Fourteen Different Activated Sludges*

Rods 1.5 to 3.5 μ long, width 1 to 2 μ. Young cultures showed zoogleal masses with individual rods distinguishable and large numbers of free swimming cells. Old cultures showed zoogleal masses, individual cells in the masses were not distinguishable, few free-swimming cells. Free cells actively motile by means of a polar flagellum. No spores. No involution forms. Capsule ½ to 2 times as thick as bacterium. Gram negative.

Nutrient broth: slow growth, gelatinous masses develop, young cultures turbid, older cultures clear even when shaken, pH increases from 7.0 to 8.5.

Agar colonies: very small, pin point, extremely limited growth.

Gelatin stab: very slight growth, no liquefaction.

Starch broth (0.2 per cent): slight growth, no hydrolysis.

Carbohydrate broth (glucose, lactose, maltose, galactose, salicin): moderate growth and floc formation, no acid or gas, pH increased from 7.0 to 7.9.

Aerobic, resistant to anaerobiosis.

Sewage: rapid growth when aerated, forms brown flocculent masses, pH increased from 7.4 to 8.7.

Microscopic observation of the growing floc revealed that individual cells disengaged from the sludge mass and darted quickly away. In young, actively growing cultures, the floc appeared composed of a mass of rods and individual cells which could be clearly distinguished under the high power of the microscope. When test tubes containing young cultures were shaken vigorously, a good deal of dispersion of the floc could be obtained with an increase in turbidity of the supernatant. As the culture aged, the coherency of the floc increased and only few free swimming cells could be seen with the high power. Generally in old cultures, the zoogleal flocs appeared under the microscope as gelatinous masses and separate cells could not be seen except in a few cases and these were at the outer fringes of the zoogleal floc. Shaking of the mature cultures caused very little dispersion of cells, but instead a mechanical breaking of the flocs into smaller ones. No increase in turbidity of the clear supernatant was observed in this case. Microscopic examination of the supernatant liquid confirmed these phenomena. Spores were not observed at any stage of culture and involution forms were absent. All the zoogleal cultures were strictly aerobic but were surprisingly resistant to anaerobiosis, as they survived lack of oxygen for 250 hours at 30° C. in nutrient broth under vaspar seals.

The organisms grew somewhat slowly in nutrient broth to which had been added separately 0.5 per cent glucose, lactose, maltose, galactose and salicin. Brom cresol purple was used as the indicator. Neither acid nor gas was produced by any of the cultures in any of the carbohydrate broths although zoogleal flocs had developed in all. The pH of the carbohydrate broths rose from 7.0 to approximately 7.7–7.9 in 8 days incubation at 30° C. In this same time of incubation at 30° C., the cultures raised the pH of nutrient broth from 7.0 to approximately 8.5. All cultures were alike in this respect. The rise in pH indicated that the zoogleal bacteria either did not attack the carbohydrates to produce acid by-products from them; or produced alkaline materials from the proteins which neutralized the acids produced; or decomposed the acids as rapidly as they were formed.

While growth occurred in nutrient broth containing 0.2 per cent starch, hydrolysis of the starch was not observed. Only very slight growth was obtained in gelatin, which was not liquefied. Growth of the zoogleal cultures was singularly depressed in agar media. Concerning growth of *Zooglea ramigera* on solid media, Butterfield states, "no growth of the organism was obtained at any time on standard agar and in gelatin, scanty growth on special sludge agar and moderate growth on nutrient agar containing 10 per cent ascites fluid." It was observed however that plating out of pure cultures of zooglea in plain nutrient agar showed subsequent development of very small colonies visible only with the low power of the microscope. Colonies restricted to the depths of the agar were quite loose and formed a tree-like floc almost identical with those found in liquid media. Sufficiently high dilution of the pure culture was used in plating to warrant the conclusion that the agar colonies observed were not zoogleal flocs mechanically incorporated in the agar during the plating-out process and had developed during incubation. Surface colonies were very few, but those that formed were of pin point size. No growth was obtained on agar slopes.

The zoogleal cultures grew vigorously in cotton-filtered heat-sterilized sewage to form approximately ten times the amount of floc in two days aeration at 20° C. with one transfer of sewage as compared with the amount of floc formed in nutrient broth in 8 days at 30° C. under quiescent conditions. The pH of the sterile sewage increased from 7.4 to 8.4 in two days. The apparent inert characteristics of the zoogleal cultures growing in ordinary bacteriological media was attributed to the very low concentration of zoogleal floc in the test tubes and to the lack of aeration.

In order to elucidate more clearly the action of the zoogleal bacteria on pure organic compounds, one of the zoogleal cultures was built up in sewage to concentrations of 1000 to 1500 p.p.m. suspended solids, which was several hundred times greater than that present in a test tube culture of the organism.

Physiological Studies of Pure Culture Sludges.—The zoogleal bacterium was grown in cotton-filtered heat-sterilized sewage containing 1000 p.p.m. glucose and 100 p.p.m. urea and aerated under sterile conditions in inverted flasks illustrated in Figure 1. Air under pressure was forced through large bottles containing concentrated sodium hydroxide to remove CO_2, then through 2 ft. of sterile cotton, through a sterile pyrex glass line and into flasks A and B, which prior to inoculation with pure culture zooglea bacteria had been sterilized as a complete unit. The flasks contained cotton-filtered sewage, glucose and urea. Supernatant liquor after sedimentation was decanted and replaced by the same nutrients as above. When the desired concentration of pure culture sludge was reached, the mixture was settled and the supernatant liquid siphoned off. Sterile sewage plus the test organic compound were added; aeration commenced, and the appropriate analyses made to detect breakdown of the pure organic compound. At the end of each test, the pure culture sludge was settled, and the supernatant removed. Additional sterile sewage was added plus the next compound for examination. Tests for the breakdown of glucose, lactose and galactose were made by analyzing for reducing sugars in the supernatant at the start and end of each aeration period. Hydrolysis of proteins through amino acid state to ammonia was detected by analyzing the supernatant liquid for ammonia nitrogen, an increase in this latter form of nitrogen taken to connote protein hydrolysis. The bacterial oxidation of soaps of oleic and butyric acids was detected by measuring the release of CO_2 during aeration of two flasks containing equal amounts of pure culture sludge floc, sewage and urea, with one flask containing the soap and the other serving as control.

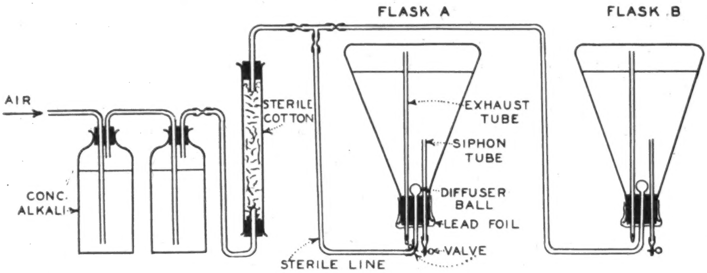

FIG. 1.—Apparatus for aeration of pure culture sludges under sterile conditions.

The action of the pure culture zooglea bacteria on carbohydrates is presented in Table II. Glucose, lactose and starch were rapidly decomposed. The absence of any reducing sugars indicated also the breakdown of the hydrolyzed products of lactose (galactose and glucose).

The proteolytic activity of the zooglea bacteria was observed by an increase of ammonia nitrogen in the supernatant containing the protein under test (Table III). Gelatin, peptone and casein were all decomposed by the pure culture sludge.

TABLE II.—*Aerobic Decomposition of Carbohydrates by Pure Culture Zoogleal Sludge*

Pure compound	Period of aeration	Sludge floc concentration	Urea concentration	Carbohydrate	
				Initial	Final
	Hours	P.p.m.	P.p.m.	P.p.m.	P.p.m.
Glucose	5	1500	100	1000	0
Lactose	12	500	100	800	0
Galactose	12	500	100	(from) (lactose)	0
Starch	4	800	100	400	0

TABLE III.—*Hydrolysis of Proteins by Pure Culture Zoogleal Sludge*

Pure compound	Period of aeration	Sludge floc concentration	Ammonia-nitrogen in liquid		
			Initial	Final	Increase
	Hours	P.p.m.	P.p.m.	P.p.m.	P.p.m.
Gelatin, 500 p.p.m.	16	500	20	130	110
Peptone, 500 p.p.m.	16	500	20	100	80
Casein, 500 p.p.m.	16	500	20	90	70

Oxidation of soaps of oleic and butyric acids by pure culture sludge is demonstrated in Table IV. Flasks containing the sodium butyrate and sodium oleate showed an increase of CO_2 release of 134 and 257 per cent respectively over the control flasks when 1000 and 1300 p.p.m. pure culture sludge was used.

TABLE IV.—*Oxidation of Soaps of Oleic and Butyric Acids by Pure Culture Zoogleal Sludge*

Materials present with pure culture sludge	Period of aeration	Sludge floc concentration	Urea	CO_2 released	Increase of CO_2
	Hours	P.p.m.	P.p.m.	Mgms.	Per Ct.
Sewage	14	750	50	19.0	—
Sewage—1000 p.p.m. sodium butyrate	14	750	50	44.5	134
Sewage	14	500	50	12.6	—
Sewage—1300 p.p.m. sodium oleate	14	500	50	45.0	257

Physical Characteristics of Pure Culture Zoogleal Floc in Sewage. —When sterile carbohydrate and urea solutions were added to the cotton-filtered sterile sewage containing the pure culture sludge, growth of the sludge floc and free cells was stimulated markedly. The rapid increase in free cells increased the turbidity of the liquid and impaired somewhat the clarifying activity of the pure culture sludge on the sewage present. Only when these readily available nutrients were removed and several transfers of sterile sewage made with continuous aeration for 5 or 6 days did the cultures regain their clarifying activity. When these readily available materials were added to natural activated sludge however, no increase in turbidity was noticed. This can probably be attributed to activity of bacteria-consuming protozoa ever present in natural activated sludge.

The pure culture floc produced in solutions of synthetic compounds such as glucose, urea and mineral salts was white and flocculent, while those sludges built up in sterile sewage alone were brown and resembled very closely natural activated sludge.

During aeration of the zoogleal floc in the presence of sewage, the size of the floc was dependent upon the air supply. When air was supplied at a low rate the sludge floc was large and flocculent, but when a high rate was used, the floc was mechanically broken by the turbulence of the mixture. When aeration was discontinued, the smaller pure culture flocs coalesced first to form larger ones before settling. In some instances these flocculent masses were upward of ½ inch in diameter. These large flocs settled very rapidly. Pure culture zoogleal sludges were less tenacious than natural activated sludges under the effect of agitation. This was probably due to the absence in the pure culture zoogleal sludge of stalked protozoa and filamentous organisms, which exert a binding action upon the zoogeal floc in natural activated sludge. While natural activated sludges settled progressively with time, the pure culture sludges settled rapidly to a maximum compaction in about ten minutes, but without further compacting. The settling ability of the pure culture sludges is compared with natural activated sludges in Table V. Settling indices of natural activated sludges ranged from 1040 to 100. Mohlman (7) reported a sludge index of 55 for rapidly settling sludge. The settling index of the pure culture sludge represents an average of six different analyses, all of which varied not more than 10 per cent from each other. The rapidity of coalescense of the floc particles of the pure culture sludges

TABLE V.—*Settling Characteristics of Pure Culture and Natural Activated Sludge*

Source of sludge	Sludge concentration	Volume occupied by sludge [1]	Sludge index
	P.p.m.	Cc.	
Madison-Chatham, N. J.	479	500	1040
Madison-Chatham, N. J.	1706	820	480
Tenafly, N. J.	1303	310	238
Madison-Chatham, N. J.	1889	250	132
Hillsdale, N. J.	1096	110	100
Literature [2]	1000	55	55
Pure culture zoogleal sludge in sewage [3]	1300	70	54

[1] One liter settled, 30 minute settling period.

[2] Mohlman, *Sewage Works Journal* **6**, 121 (1934).

[3] Average of 6 analyses, variation not greater than 10 per cent among sludges.

was a function of the concentration of the sludge, as coalescence occurred more rapidy with greater concentration of sludge. An increase in temperature of the liquid favored coalescence of the floc particles and settling was more rapid in the warmer liquid, probably due to a lowering of the viscosity of the water.

Bulking of Pure Culture Sludge.—While the work on activated sludge under investigation did not include a study of the phenomenon of bulking, the availability of the pure culture sludges was utilized in connection with the studies of this problem in the laboratory. Attempts were promulgated to produce bulking in pure culture sludges by means of the same conditions which favored bulking of natural activated sludges. The pure culture zoogleal organism was built up to the desired concentration in sterile sewage. One liter of pure culture sludge containing 1500 p.p.m. suspended solids was settled, supernatant removed and the sludge divided into two fractions. One received sterile sewage plus 800 p.p.m. glucose and 20 p.p.m. urea every 8 hours, while the control fraction received only sterile sewage. Both flasks were aerated at the same rate. At intervals the sludges were settled to test for bulkiness or impaired settling. At the end of 24, 48 and 72 hours' aeration, under these conditions, the pure culture sludge receiving high carbohydrate and urea nitrogen was not bulky and possessed the same settling rate as the control sludge. Following this, the supernatant liquid was removed, the settled sludges combined, mixed and divided equally again. The 8-hour dosage of glucose was increased to 2000, 3000, and 4000 p.p.m. and urea to 20, 30 and 40 p.p.m. respectively. Continuous aeration of the pure culture sludge for ten days in the presence of high carbohydrate and urea nitrogen failed to produce bulking.

During the physiological studies on the pure culture zoogleal bacteria previously mentioned, the settling ability of the pure culture sludges was observed in the presence of large amounts of various organic compounds. Aeration of the pure culture sludges in the presence of the following compounds was found not to produce bulking:

Substance	P.p.m.
Lactose	800
Starch	400
Gelatin	500
Peptone	500
Casein	500
Sodium butyrate	1000
Sodium oleate	1300

DISCUSSION

During the isolation of zoogleal cultures from activated sludges and study of their oxidative ability by Butterfield, Ruchhoft and McNamee (3) the statement was made, "the fundamental characteristics of the bacteria isolated suggest that they all belong to the same general group of organisms as the zooglea-forming bacterium described by Butterfield." Bacteriological analyses of these different cultures were not reported, the above conclusion evidently being reached by the similarity existing between the different cultures in morphology, floc formation and oxidative ability.

The bacteriological analyses of the 14 zoogleal cultures isolated in our laboratory from activated sludge demonstrated that the zoogleal organisms appeared sufficiently alike morphologically and culturally to be classed either as one species or in one genus and that these organisms were indistinguishable from the zoogleal bacterium described by Butterfield. This substantiates the aforementioned suggestion by Butterfield, Ruchhoft and McNamee.

Direct microscopic examination of natural activated sludges showed them to consist predominantly of zoogleal flocs. Mechanical grinding of these flocs followed by staining showed them to be composed almost entirely of Gram negative rods, existing evidently within these gelatinous masses. In view of these facts, activated sludge can be considered to be normally composed of zoogleal flocs of *Zooglea ramigera,* an organism which has the capacity to grow in liquid media in the form of flocculent masses which remain fairly intact under sufficient aeration to maintain aerobic conditions. In addition, there is usually incorporated in the floc some organic material as well as some protozoa and filamentous organisms.

Attention should be called to the differences in results obtained with regard to the biochemical reactions of the zoogleal organism by the two different methods employed. In ordinary bacteriological technic it is customary to inoculate small numbers of organisms into culture media and determine the specific reactions brought about after a period of incubation. When this method was applied to zoogleal organisms it failed to reveal the specific carbohydrate and proteolytic biochemical changes. On the basis of these tests alone, the zoogleal organism would be considered inactive. However when large masses of the organism were introduced into appropriate substrates containing different sugars, proteins and fatty materials, and aerated, the ability of the organism to attack these materials was definitely demonstrated. From these results it appears that both large inoculations and aeration are essential to detect the specific biochemical changes. Butterfield and Wattie (4) demonstrated the relation between the rate of oxidation of food and the number of living cells. They estimated that the number of zoogleal organisms in pure culture sludge of 1000 p.p.m. suspended solids to be about 10 billion per cc. The maintenance of a large amount of sludge is therefore not only necessary for the possible physical adsorption of the sewage impurities but also for the rapid biochemical oxidation of these materials in order to maintain the process on an even keel.

Observation was made of the fact that cultures of *Zooglea ramigera* in nutrient and sugar broths when young possessed large numbers of free swimming cells which produced turbidity. Microscopic examination of the young flocs in these tubes showed them to be constituted mainly of masses of rods, the individual bacterial cells being easily distinguishable. In the same cultures which were one or two weeks older there was a great reduction in the free swimming cells and an accumulation of gelatinous flocs. There was no turbidity in the supernatant liquid even after shaking of the culture. Individual cells could not be distinguished in the zoogleal masses in the older cultures except occasionally at the outer edges of the flocs. It was observed that the capsular wall of the free-swimming cells increased in size with the age of the culture and this phenomenon was paralleled by both a decrease of motility of the cells and an increase in the amount of zoogleal mass. The merging of the individual bacterial cells into the zoogleal mass is apparently a normal manifestation of growth, and is not likely due to the increase in the amount of capsular material with the age of the organism.

It was also noted that addition of large amounts of carbohydrates and urea to pure culture sludge previously built up in sterile sewage impaired the clarifying activity of the sludges on sewage. This was caused by a great increase in the numbers of free swimming cells of the zooglea bacteria in the supernatant liquid. There was also an increase in the amount of sludge floc. The cultures regained their clarifying power only after daily transfers of sterile sewage, devoid of added nutrients, and continuous aeration in the absence of readily available food for periods of 4 to 5 days.

Pure culture sludge was found to settle to maximum compaction in approximately 10 minutes while natural activated sludges settled at a much slower rate and then progressively with time. The rapid settling and compaction of the pure culture sludge was ascribed to the absence of stalked protozoa and filamentous organisms often found in natural activated sludge. The pure culture sludge index was 54, approximately the same as that of a rapid settling activated sludge.

Extended attempts to induce bulking of the pure culture zoogleal sludges under conditions which would normally produce gross bulking of natural activated sludge, met with failure. Large amounts of glucose, lactose, starch, gelatin, peptone, casein, sodium oleate and sodium butyrate had no effect on the settling capacity of the sludges beyond a normal stimulation of growth. The conclusion drawn was that sludge zoogleal organisms cannot be made bulky with these materials. This points to the importance in the bulking phenomenon of filamentous organisms such as *Sphaerotilus* which are stimulated by excess carbohydrates and other environmental conditions to overgrow natural activated sludge.

Analyses of pure culture zoogleal sludges which were made available from studies of carbon and nitrogen transformations are presented in Table VI. These sludges were built up in sterile sewage and analyzed at various periods of aeration. The sludge indices of pure culture sludges Z–1 and Z–2 were approximately the same. Contrary to the wide variation of carbon and nitrogen content which is found in natural activated sludges, the composition of the pure culture

TABLE VI.—*Chemical Composition of Pure Culture Zoogleal Activated Sludge*

No.	Description	Sludge index	Total solids	Organic solids	Ash	Total nitrogen	Total carbon	Nitrogen	Carbon	C/N
			Mgm.	Mgm.	Per Ct.	Mgm.	Mgm.	Per Ct.	Per Ct.	Ratio
1	Zooglea bacteria Z–1 (0 hours)	45	1347	1183	12.2	128.5	588.0	9.5	43.7	4.6 : 1
1	Zooglea bacteria Z–1 (4 hours)	53	1387	1203	12.5	133.8	635.0	9.6	45.7	4.7 : 1
1	Zooglea bacteria Z–1 (24 hours)	56	1234	1064	13.8	129.2	560.6	10.5	45.5	4.3 : 1
2	Zooglea bacteria Z–2 (0 hours)	48	1777	1573	11.5	172.0	795.0	9.7	44.8	4.6 : 1
2	Zooglea bacteria Z–2 (4 hours)	53	1845	1624	11.4	180.6	836.0	9.8	45.3	4.2 : 1
2	Zooglea bacteria Z–2 (24 hours)	44	1655	1442	12.9	175.0	736.0	10.5	44.5	4.2 : 1
	Average				12.4			9.9	44.9	4.5 : 1

sludges was found to be fairly constant. The percentage nitrogen varied from 9.5 to 10.5 percentage carbon from 43.7 to 45.5 and percentage ash from 11.4 to 13.8. Average percentage ash was 12.4; average nitrogen 9.9; average carbon 44.9 and C/N ratio 4.5/1.

SUMMARY AND CONCLUSIONS

A study of the morphological and cultural characteristics of 14 cultures of zoogleal bacteria isolated from as many different activated sludges was made. These cultures, capable of producing flocculent masses simulating good natural activated sludge, were found to be sufficiently alike to be classed either as one species or as one genus and were also indistinguishable from the zoogleal bacterium, *Zooglea ramigera* described in 1935 by Butterfield.

Natural activated sludge is comprised principally of flocculent masses produced by *Zooglea ramigera.*

In young tube cultures of *Zooglea ramigera* and in pure culture zoogleal sludges fed large amounts of carbohydrates and proteins there were large numbers of free swimming cells in addition to the flocculent masses. In older tube cultures and in pure culture sludges aerated without food for several days, a marked decrease in numbers of free swimming cells occurred. Pure culture sludges of *Zooglea ramigera* were found to decompose simple and complex carbohydrates and proteins and soaps of fatty acids, similar to natural activated sludges.

Settling of pure culture sludges was rapid, approximately 10 minutes being required to produce maximum compaction. The average pure culture sludge index was 54, equivalent to that of an excellent, rapid settling activated sludge. Sludge indices of natural activated sludges varied from 55 to 1040, when subjected to the same food and environmental conditions.

The mechanism of settling of the pure culture sludges was characteristic, small floc particles coalescing into larger ones which settled rapidly.

Under conditions which would produce extreme bulking of natural activated sludges, pure culture sludges were stable and could not be made bulky.

The chemical composition of pure culture zoogleal sludges was fairly constant. Average carbon content was 44.9 per cent, nitrogen content 9.9 per cent and C/N ratio was 4.5/1.

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FILTRATION TESTS WITH ELUTRIATED AND UNELUTRIATED DIGESTED SOLIDS

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The washing of sludge prior to filtration, in order to reduce the amount of coagulant required, is a relatively new process. Results of filtration tests on elutriated (washed) sludge have been published by Genter[1] and by Keefer and Kratz.[2] One of the first installations of the Genter Sludge Treatment Process was made at the Washington, D. C. sewage treatment plant. The structural features of the elutriation unit have been described by Marston.[3]

Since the start of operation, only elutriated sludge has been filtered. The elutriated sludge is conditioned with between 2 and 3 per cent ferric chloride. Under ideal conditions, the elutriated sludge can be filtered with about 1.5 per cent ferric chloride. By "ideal conditions" is meant a uniform delivery of elutriated sludge to the conditioning tanks and new filter cloths on all the filters. For evaluating the benefits of elutriation, it is necessary to compare the same sludge before and after elutriation, because different sludges may have quite different filtering properties. The primary object of this study was to determine the filtering properties of digested sludge before and after elutriation. These results are presented in the second part of the paper. In the first part of the paper, some experiments are presented to show how elutriation functions. The sludge used in the tests was digested primary solids.

Methods

The course of elutriation can be followed by any one of a number of tests. Genter, Keefer and Kratz have employed the amino-ammonia nitrogen test. With sludges containing practically all of the amino-ammonia nitrogen in the form of free ammonia, such as well digested sludges, it is possible to get the same result by determining the free ammonia. As shown in Table I, the alkalinity of the water associated with the sludge can be used to measure the degree of elutriation. The sludge mixture is filtered through a dry filter and 5 ml. of the filtrate are titrated with N/50 acid, using methyl orange indicator.

For determining the amount of ferric chloride required to condition a sludge, the sludge filtration test described by Genter[1] was employed. A few slight changes were made in Genter's procedure. The method, as used, consists of weighing out a 200-gram sample of the sludge in a beaker. A known volume of a 10 per cent ferric chloride solution is then added and the mixture stirred and allowed to stand 10 minutes. The sample is then poured onto a moistened filter paper in a 12.5 cm. Buchner funnel. A stop watch records the time from the application

TABLE I.—*Alkalinity as a Measure of Elutriation*

Volume Sludge	Volumes Water	Alkalinity ($CaCO_3$) Observed P.P.M.	Alkalinity ($CaCO_3$) Calculated P.P.M.
1	0	3525	—
1	1	1730	1792
1	3	900	926
1	5	620	638
1	15	285	277
1	63	111	114
0	1	60	—

of the vacuum until a definite volume of filtrate is obtained. Genter determines the time it takes for the vacuum to break. It was found that a slight tilting of the funnel caused an uneven cake and duplicate samples often failed to agree. For this reason, it was decided to measure the volume of filtrate obtained when the vacuum broke and in the actual tests to use a slightly smaller volume as an end point. With this procedure duplicates have agreed very well. To compare sludges, a series of tests were made with each sludge, using varying amounts of ferric chloride. The filtration times are plotted against the per cent of ferric chloride added to the sludge (dry basis). From the curves, the ferric chloride doses of the different sludges for the same filtration times are obtained.

Laboratory Elutriated Sludge.—To study the effect of sludge washed with large quantities of water, it was necessary to use sludge elutriated in the laboratory. The digested sludge was mixed with known volumes of water, allowed to settle, and the supernatant siphoned off. In the case of the sludge marked 15 volumes of water and 63 volumes of water, the elutriated sludge was elutriated a second and a third time. That is, instead of adding 63 volumes of water to one volume of sludge, 1 volume of sludge was mixed with 3 volumes of water and allowed to settle, the supernatant was removed, and 3 more volumes of water added. The mixture was again allowed to settle, the supernatant removed and the sludge washed a third time with 3 volumes of water. For example, 100 ml. of a solution containing 64 p.p.m. of a substance is diluted to 400 ml. (addition of 3 volumes). The solution then contains 64/4 or 16 p.p.m. If 100 ml. of this solution is diluted to 400 ml., the solution will contain 4 p.p.m. The third treatment reduces it to 1 p.p.m. or 1/64 of its original concentration.

The relative amounts of ferric chloride required for the same filtering time are shown in Fig. 1. The amount of ferric chloride needed to condition these sludges is approximately inversely proportional to 1 plus the volumes of wash water, up to 5 volumes. The ferric chloride requirement is almost directly proportional to the alkalinity in this series. The alkalinity values are those given in Table I. In this series, considerable sludge was removed with the wash water. The original sludge contained 7.8 per cent solids, after being elutriated with 3 volumes of water the solids had dropped to 6.4 per cent, with 15 volumes of water the sludge contained 5.2 per cent solids and with 63 volumes of water the solids were down to 4.9 per cent. That is, the sludge was not only washed but fractionated. It is interesting to note, however, that the remaining 63 per cent of the solids were very easy to filter. In fact, the sludge filtered in 217 seconds with no ferric chloride. This shows clearly that it is finely divided material, or the substances in solution which consume the ferric chloride.

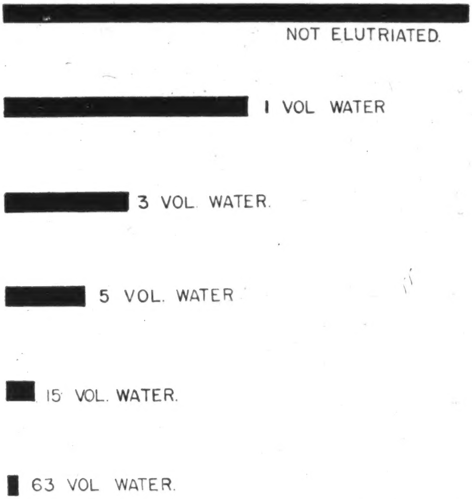

FIG. 1.—Relative doses of ferric chloride for varying degrees of elutriation.

TABLE II.—*Filtration Times of Sludge Liquor*

Per Cent $FeCl_3$	Filtration Time, Seconds
58	135
81	93
105	62
116	36

The same conclusion can be drawn by working with the liquor associated with the sludge. If digested sludge is allowed to settle and the sludge liquor siphoned off, it is found that almost as much ferric chloride is needed to filter the liquid as is required if the sludge is present. Filtration data for sludge liquor are given in Table II. The sludge liquor contained 0.4 per cent solids, so that a dosage of ferric chloride of 116 per cent (dry solids basis) is 0.5 grams per 100 grams of liquor. The same amount of ferric chloride (0.5 gram) added to 100 grams of a 10 per cent sludge mixture is a dosage of 5 per cent.

Since the liquor associated with the sludge appeared to be the ferric chloride-consuming part of the digested sludge mixture it was decided to study its properties. The analysis of the liquor is given in Table III.

TABLE III.—*Composition of Sludge Liquor*

	P.P.M.
Total Solids	1872
Suspended Solids	268
Ash	827 or 44.2%
Total Nitrogen (Kjeldahl)	840
Free Ammonia Nitrogen	718
5-Day B.O.D.	525
Alkalinity ($CaCO_3$)	3627
Volatile Acid (Acetic)	200
pH	7.7

Ash Analysis	Per Cent
SiO_2	13.8
Al_2O_3	37.8
CaO	34.6
MgO	5.9
Fe_2O_3	5.7

This liquor is in equilibrium with a gas containing 30 to 33 per cent carbon dioxide. The relatively high volatile content (55.8 per cent) is not all organic matter. If the inorganic constituents are calculated as carbonates, hydroxides, and silicates, the total and volatile solids figures are in good agreement with the values observed for the sludge liquor. After drying, only 2 p.p.m. of free ammonia was recovered, indicating that about 4000 p.p.m. of ammonium bicarbonate had been lost on drying and consequently did not appear in the total solids figure. This is by far the largest single component of the liquor and can account for about 70 per cent of the observed bicarbonate alkalinity. This agrees with Genter's observation that ammonium bicarbonate added to elutriated sludge counteracts the value of elutriation.

Experiments were then run with elutriated sludges to which were added enough ammonium salts to bring the ammonium nitrogen back to the value observed in digested sludge. Ammonium ion added as ammonium nitrate and ammonium chloride was without effect on the filtering rates. However, when a solution of ammonium carbonate was added, the ferric chloride dosage had to be increased. This indicated that it was probably the carbonate and not the ammonium ion which was reacting with the ferric chloride. Curves are given in Fig. 2 which show the effect of adding a carbonate and a bicarbonate to elutriated sludge. In the case of the ammonium salt, the alkalinity (calculated as $CaCO_3$) was raised to 4580 p.p.m. and enough sodium bicarbonate was added to raise the alkalinity to 3360 p.p.m. The elutriated sludge with the same bicarbonate alkalinity as digested sludge required almost as much ferric chloride as the digested sludge. (See Fig. 4 for unelutriated digested sludge.) The fact that the bicarbonates are responsible for the high ferric chloride dosages with digested sludges agrees with the fact that lime is an aid to the filtering of digested solids but is of little value when conditioning an elutriated sludge. Also any agent like formalin which reacts with the ammonia would release the bound CO_2 and thus remove the bicarbonate from the solution.

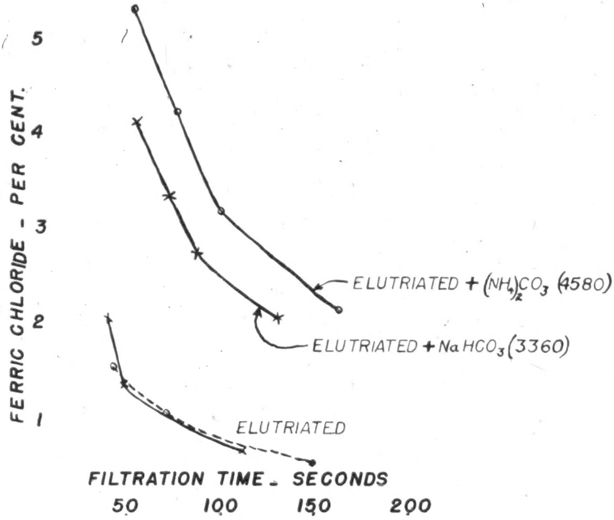

FIG. 2.—Elutriated sludge with added bicarbonate.

To recapitulate, it has been shown that a large portion of the ferric chloride used to condition digested sludge solids reacts with the liquor associated with the sludge and hence is lost as far as conditioning the sludge is concerned. The removal of this liquor by washing results in a considerable saving of ferric chloride. From analysis of the liquor, it is found that ammonium bicarbonate is present in large quantities. Filtration tests on washed sludges to which ammonium salts and bicarbonates were added indicate that the amount of ferric chloride needed to condition the sludge is related to the bicarbonate concentration and influenced very little by the ammonium ion. The removal of bicarbonates by acids at once suggests itself as a check on this theory.

It is not the purpose of this paper to discuss the mechanism of sludge conditioning but it must be remembered that the addition of acid not only removes bicarbonates by liberating CO_2 but can also alter other properties of the sludge. The additional ion introduced by the acid might be as undesirable as the bicarbonate ion, moreover, possibility of silicic acid being precipitated exists. Negative results with acid would not necessarily disprove the theory that the removal of bicarbonates accounts for a large part of the saving in ferric chloride when digested solids are elutriated prior to filtration.

Working with the sludge liquor, it was found that the amount of acid added had considerable influence on the amount of conditioner required. For example, three 200-gram samples of liquor were taken, 0.4 ml. of conc. HCl was added to one, 0.9 ml. of conc. HCl, to the second, and the third was used as a control. The filtering times with the same dosage of ferric chloride were 200, 11, and 110 seconds respectively. The overdose of acid almost doubled the filtering time of the liquor while the smaller dose of acid permitted the liquor to be filtered in one-tenth the time. The smaller dose of acid is capable of removing about 2500 p.p.m. of bicarbonate alkalinity, the larger dose in addition to removing the alkalinity altered other properties of the liquor. The addition of acid to the mixture of liquor and solids, as drawn from a digestion tank, was then tried.

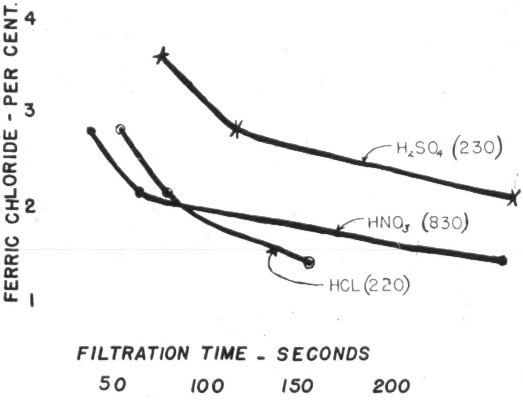

FIG. 3.—Digested sludge treated with acids.

A series of tests were run with digested solids using various acids. The filtration curves are plotted in Fig. 3. The residual alkalinities of the sludge liquor after the addition of acid are given on the respective curves. Lower doses of ferric chloride were needed when nitric and hydrochloric acids were employed than when sulfuric acid was used. This is not surprising in view of the fact that ferric sulfate and chlorinated copperas are known to be inferior to ferric chloride as conditioning agents. In all cases, the amount of ferric chloride was lower than that required by the straight digested sludge. This is taken as additional proof that the removal of bicarbonates is a vital factor in the elutriation of digested solids.

The removal of bicarbonates by elutriation agrees with the findings of Genter. He used the amino-ammonia nitrogen test to follow elutriation and it has been shown that the bicarbonate test can be used for the same purpose. Both tests are measures of ammonium bicarbonate. The ammonia combines with the carbon dioxide in the digestion mixture forming ammonium bicarbonate. Any test for ammonia is an indirect test for bicarbonate and conversely about 70 per cent of the bicarbonate is present as an ammonium salt. The presence of ammonium bicarbonate in the digested sludge is responsible for its high ferric chloride demand and its removal by elutriation results in a much lower ferric chloride demand.

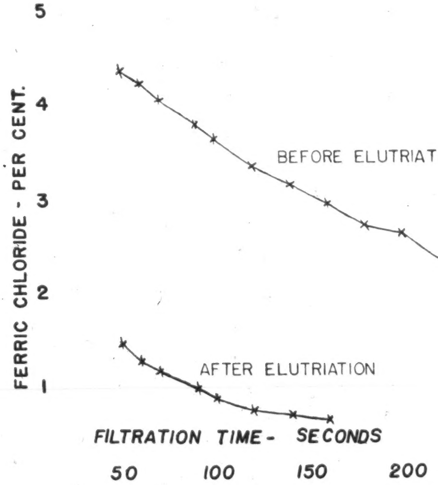

FIG. 4.—Elutriated and unelutriated solids.

Plant Elutriated Sludge.—In these tests, composite examples of digested sludge going to the elutriation unit were compared with composite samples of elutriated sludge leaving the elutriation unit. During these tests, sludge was elutriated with 2.5 volumes of water, employing counter-current elutriation. That is, the final wash water is returned by gravity to the first mixing tank where it comes in contact with the digested sludge from the digestion tanks. After flowing into the first pair of settling tanks, the supernatant leaves the system and the settled sludge is pumped into the second mixing tank together with 2.5 volumes of Potomac River water. From the second mixing tank the mixtures passes into a second pair of settling tanks. The settled sludge is then pumped to the dewatering plant and the supernatant, mentioned above as the final wash water, returns to the first mixing tank. The elutriate contained 0.5 per cent solids, so that the percentage of digested sludge remaining after washing is higher than those sludges elutriated a corresponding amount in the laboratory.

TABLE IV.—*Digested Sludge*

Alkalinity	pH Filtrate	Solids Per Cent	Volatile Per Cent	$FeCl_3$ Per Cent	Filtration Time-Sec.
3865	7.6	7.5	41.7	2.7	165
	7.3			4.0	59
	7.2			5.3	34
3760	7.6	9.4	40.8	2.1	227
	7.3			3.2	200
	7.2			4.3	63
3830	—	10.3	41.8	—	—
	7.3			3.0	170
	7.2			3.9	85
3820	7.5	9.3	42.1	2.0	250
	7.4			3.2	70
	7.1			4.3	49
3800	7.5	8.7	42.3	2.3	265
	7.4			3.4	123
	7.1			4.6	61
3610	7.5	8.8	41.5	2.3	220
	7.4			3.4	134
	7.3			4.5	51
3625	7.5	8.2	41.1	2.4	296
	7.4			3.7	101
	7.3			4.9	51
3628	7.5	10.5	40.2	1.9	240
	7.3			2.9	118
	7.2			3.8	54
3680	7.5	9.1	41.3	2.2	185
	7.3			3.3	110
	7.2			4.4	60
3640	7.6	9.1	41.1	2.2	210
	7.4			3.3	126
	7.2			4.4	65
3710	7.6	10.4	41.0	1.9	301
	7.4			2.9	130
	7.2			3.8	86
3600	7.7	7.7	38.7	2.6	204
	7.5			3.9	102
	7.3			5.2	78

Results of these tests are given in Tables IV and V. The filtration times for each series were plotted against the per cent ferric chloride used to condition the sludge. Thus, twelve curves were obtained for the digested sludge and also for the elutriated sludge. From these curves the average dose of ferric chloride for filtration times of 50, 60, 70, 90, 100, 120, and 140 seconds was obtained. These average values are plotted in Fig. 4. The median values are not plotted but the curves are practically identical with the average curves. The average temperature of the digested sludge was 26° C. and of the elutriated, 23° C. For the longer filtration times, the amount of ferric chloride required to condition the elutriated sludge is about one-fourth of that required by the digested sludge. For the shorter filtration periods, this value is about one-third. It is not shown on these curves but both curves break rather sharply at higher doses of ferric chloride. For example to filter the digested sludge in 35 seconds it would require a dosage of ferric chloride somewhere between 5.5 and 7.5 per cent and for elutriated sludge between 1.8 and 2.5 per cent. The digested sludge elutriated in

TABLE V.—*Elutriated Sludge*

Alkalinity	pH Filtrate	Solids Per Cent	Volatile Per Cent	$FeCl_3$ Per Cent	Filtration Time-Sec.
610	7.3	8.5	40.7	0.6	141
	6.8			1.2	52
	6.5			1.8	37
615	7.2	8.5	39.4	0.6	170
	6.8			1.2	54
	6.5			1.8	34
585	7.3	9.0	41.4	0.6	190
	6.9			1.1	63
	6.5			1.7	50
575	7.3	8.8	41.4	0.6	170
	6.9			1.1	74
	6.8			1.7	40
515	7.2	9.0	38.9	0.6	150
	6.6			1.1	53
	6.4			1.7	37
498	7.2	7.6	40.6	0.7	112
	6.8			1.3	46
	6.5			2.0	31
495	7.2	8.8	39.9	0.6	127
	7.0			1.1	89
	6.6			1.7	36
410	7.2	9.2	39.9	0.5	121
	7.0			1.1	51
	6.6			1.6	32
432	7.1	8.1	39.8	0.6	127
	6.8			1.2	58
	6.5			1.8	33
427	7.2	7.9	41.3	0.6	131
	6.7			1.3	61
	6.2			1.9	41
430	7.1	8.3	41.4	0.6	150
	6.8			1.2	63
	6.6			1.8	42
480	7.2	8.0	41.6	0.6	161
	6.8			1.2	77
	6.5			1.9	48

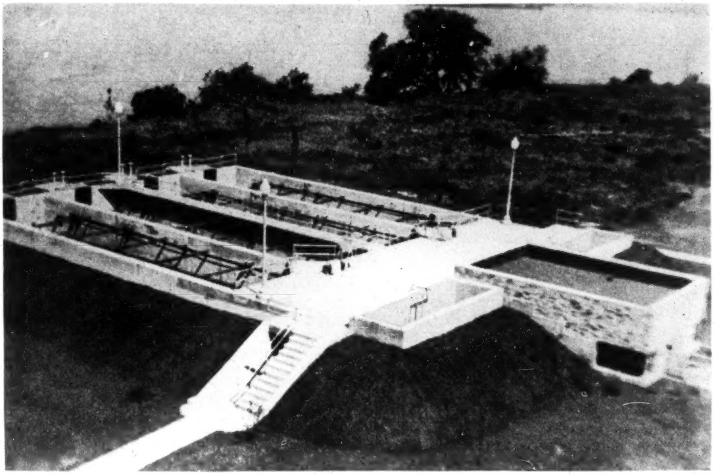

FIG. 5.—View of elutriation unit.

the plant retained more of the finely divided solids and required relatively more ferric chloride for conditioning than the sludge elutriated in the laboratory. Elutriation with 2.5 volumes of river water reduces the alkalinity to about one-sixth its original value and the sludge can be conditioned with one-third the amount of ferric chloride.

CONCLUSIONS

Digested sludge elutriated by countercurrent washing with 2.5 volumes of water can be conditioned with one-third the amount of ferric chloride.

The alkalinity test is a convenient measure of degree of elutriation.

The success of elutriation in reducing the amount of conditioner required for digested sludge can be attributed largely to the removal of ammonium bicarbonate from the sludge mixture.

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DISCUSSION OF PAPER BY PAUL D. McNAMEE, "FILTRATION TESTS WITH ELUTRIATED AND UNELUTRIATED DIGESTED SOLIDS"

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Prof. L. J. Henderson has aptly stated that "Acidity and alkalinity surpass all other conditions, even temperature and concentration of reacting substances, in the influence which they exert upon many chemical processes." In true scientific manner Mr. McNamee, in his foregoing paper, has used the sense of this statement to advance our knowledge of the function of sludge elutriation and to provide a simple means of following the effects and efficiency of this process.

McNamee's systematic investigations of the sludge liquor itself have been carried to further experimental and analytical limits than heretofore published and are therefore most enlightening. His conclusions should satisfy those who maintain it has not been shown that the soluble decomposition products, produced during digestion and accumulated in the liquor surrounding the sludge particles, are wholly or in major part responsible for the resistance of sludge to coagulation.[1]

Undoubtedly the bicarbonate radical, principally associated with ammonia in the liquor of digested sludges, is responsible for the formation of insoluble, gelatinous hydroxide precipitates when ferric and aluminum salts are added to such sludge or its liquor. This has been emphasized in previous issues of This Journal.[2, 3]

To a large extent the same is probably true in raw sludges. However, it should be remembered that in stale or septic raw sludges the parent substances for bicarbonate formation, such as carbohydrates, amino and fatty acids, can play a similar role. Furthermore, fatty acids combined with liberated ammonia not only act as peptizing or dispersion agents but also form soluble and precipitated smeary soaps with iron and aluminum salts. In other words, the precipitate forming radical of the major portion of these ammoniacal and free compounds is associated with the carboxyl or bicarbonate radicals.

Our knowledge of a scientific subject is never extensive unless we can give it some mathematical expression. McNamee uses such an expression when he states that the amount of ferric chloride needed to condition elutriated sludges is approximately inversely proportional to 1 plus the volumes of wash water, up to five volumes. This statement automatically correlates the fraction of coagulant saved to the fraction of bicarbonates removed by elutriation, within certain wide limits.

The fraction of bicarbonates or any other solute left in free solution (non-imbibed or non-adsorbed) in the sludge liquor after single stage elutriation is, under ideal conditions,

$$\frac{1}{a+1}, \tag{1}$$

wherein a is the volume ratio of elutriation water to *sludge moisture*, added to and decanted from a sludge during elutriation. This fraction is identical with the fraction expressed by McNamee, *i.e.* if the amount of ferric chloride used to condition an unelutriated digested sludge is 1, then the fraction of this amount necessary to produce equivalent coagulation of an elutriated sludge, having the same solid content, will be expressed approximately by Equation (1). The fraction of bicarbonates removed from a sludge by single stage elutriation will then be 1 minus Equation (1), or

$$\frac{a}{a+1}, \tag{2}$$

which is also the fraction of coagulant saved by elutriation.

From Fig. 1 of the foregoing paper it appears that the ferric requirements of the sludges fractionally elutriated are also roughly proportional to this inverted ratio. This seems to be true where fractional washing was made equivalent to using 15 volumes of water by single-stage elutriation.

With fractional or multi-stage elutriation the same sludge is washed n times and a is the total amount of water used. Therefore n/a volumes of water to 1 of sludge moisture are used for each wash. It is simple to demonstrate from Equation 1 that the fraction of original solute remaining after n washes is

$$\frac{1}{\left(\frac{a}{n}+1\right)^n} \quad \text{or} \quad \left(\frac{n}{a+n}\right)^n. \tag{3}$$

This equation shows how McNamee arrived at the equivalent of 15 and 63 elutriation ratios of Equation (1) while fractionating with the total ratios of 6 and 9 volumes of water in two and three washes according to Equation (3).

It can be demonstrated by algebraic calculation that the fraction of solute left after counter-current elutriation in *n tanks* is equal to

$$\frac{a-1}{a^{(n+1)}-1}. \tag{4}$$

In all of these equations it must be remembered that a is the ratio of volumes of wash water used to volume of moisture present in any sludge. This automatically accounts for solids present. Where none of the solute remains adsorbed or imbibed at higher concentrations in the sludge solids, the solute removals by extensive washing approach 100 per cent.

Data and empirical curves plotted from washing Baltimore digested sludges by these various elutriation methods approached a total removal limit of 91 per cent. This naturally led to the question of some fraction (approximately 9 per cent) of the original sludge moisture with its ammoniacal bicarbonate solute concentration always remaining imbibed within the body of the digested sludge floccules. Elutriations made at any ratio, in the normal elutriation time and without using exchange ions, failed to displace this ultimate fraction. The concentration of solute within the capillary structure of the sludge floccules was higher than in the surrounding purified moisture left after elutriation according to Equations 1, 3 and 4. If this were not true the total solute removal by elutriation could be made to approach 100 per cent instead of the 91 per cent limit actually found.

In sludges having a lower volatile content this imbided fraction was apparently less. As the sludges examined by McNamee have a lower volatile content than at Baltimore, the imbibed fraction of the Washington sludges may be distinctly lower. In any case, I lean to the opinion that some small ultimate fraction of the original solute should remain in the sludge floc in order to provide some ionized substance to react with the coagulant. Modern colloid and capillary chemistry requires such a view.

The empirical data collected at Baltimore resulted in empirical elutriation curves [4] and equations which expressed these curves. These curves were quite similar to those plotted from Equations 1, 3 and 4 and the empirical equations were likewise similar. According to these equations the fractions of total original solute left by the various elutriation methods were:

Single stage elutriation

$$\frac{b}{a + b}. \tag{5}$$

Fractional or n stage elutriation

$$\left(\frac{bn}{a + bn}\right)^n. \tag{6}$$

Counter-current in n tanks

$$\frac{b^n(a - b)}{a^{n+1} - b^{n+1}}. \tag{7}$$

The factor b was 1.327 for the sludges investigated. The remarkable property of this factor is that if there is no imbibing action, meaning that all of the solute can be washed out, the fraction of the factor in excess of 1, *i.e.* 0.327 in this case, vanishes and b becomes 1, which then makes Equations 5, 6 and 7 identical with the ideal Equations 1, 3 and 4.

McNamee states that counter-current elutriation in two tanks at Washington uses 2.5 volumes of river water to 1 of sludge and reduces the alkalinity to about one-sixth its original value. The reduction should be considerably more at this elutriation ratio. If the sludges going to elutriation average about 91 per cent moisture, as shown in his Table 4, this means that a or the ratio of water to moisture is about 2.75 to 1. As n is 2 in Equation 4, and if the river water is free of bicarbonates, the alkalinity fraction left should be about 0.09 or almost one-half of the fraction indicated.

Even using Equation 7 and $b = 1.327$ with $a = 2.75$ the fraction of original solute left is still less than the stated fraction, namely 0.108 or about one-ninth. However, as McNamee's alkalinity tests were always made in the absence of solids they show the bicarbonate concentrations in the free moisture which would be displaced practically according to ideal Equations 1, 3 and 4. His observed and calculated values in Table 1 clearly bear this out for Equations 1 and 3.

The discrepancy between observed and calculated values for plant counter-current practice is probably due either to faulty metering of sludge and water, or to bicarbonates, silt or other precipitate-forming complexes present in the river water, or to a combination of both. With pure water, using about 1.63 volumes of water to 1 of sludge having 91 per cent moisture, the value of a would be 1.79, which would leave one-sixth of the original alkalinity. With proper conditioning and piping equipment the ferric consumption should also be reduced proportionately and not to one-third. However, this comparative reduction in ferric consumption by elutriation in the field can only be made by field tests with unelutriated and elutriated sludges. Sometimes there is a considerable difference between ferric doses required in laboratory testing and in plant operation. So far I have found this due mostly to mechanical factors in plant operation and to faulty installation of conditioning and filter piping equipment, rather than to any difference in fine solids present in sludges elutriated in the plant and in the laboratory. Conditioned sludge is usually stirred far too much in the plant and held far too long in process.[4, 5] My own examination of the fine solids removed by the elutriate shows that if they are settled or centrifuged to about the same solid content as the settled washed sludge from which they are removed, and have the same bicarbonate content as this coarser sludge, the ferric dose required to produce equivalent filtration rates is not appreciably different. By changing the piping and mixing time in the Winnipeg installation the ferric dose for elutriated sludges was cut almost 50 per cent and brought nearer laboratory testing conditions, *i.e.* from about 3 per cent to about 1.5 per cent.

It was for the purpose of determining the *total* amount of soluble decomposition products present in all sludges that I sought a rapid and reliable analytical method. I initially suspected that imbibing action or adsorption of the naturally gelatinous sludge floccules might play some role in elutriation. With the available equipment I was unable to determine bicarbonates in the presence of sludge solids. However, I was able to do this through following the ammoniacal groups or radicals of the various compounds. In my opinion these compounds included bicarbonates and carboxyl groups combined with ammonia and amino acids.[6] Therefore the term "soluble ammoniacal compounds" was used in quite an extended sense.[7] Experiments by Kratz indicate that Nesslerization of sludge moisture in the presence of the sludge solids is equally as reliable as the method I used and is probably to be preferred. If the imbibed compounds cannot be washed from the sludges by normal elutriation, then McNamee's bicarbonate method is superior to any, especially in view of his analytical proof that in digested sludge liquor ammonia accounts for about 70 per cent of the precipitate-forming bicarbonates present.

In briefly mentioning his modified procedure of making filtration tests, McNamee fails to mention his own method of detecting the exact instant at which the vacuum breaks. This method, described briefly by Van Kleeck,[8] was originated by McNamee at Washington and is superior to the use of a vacuum gauge. As an indicating gadget it is about the simplest and most reliable I have seen for laboratory filtration tests.

As to the use of acid for destroying bicarbonates, my unpublished investigations on raw and digested sludges with various acidified coagulants confirm McNamee's findings. Commercial ferric chloride solutions contain some free acid to prevent hydrolysis. This makes these solutions more effective on unelutriated sludges than ferric oxychloride, *i.e.* acid free, deep red colloidal ferric chloride. The reverse is true on elutriated sludges. In fact practically neutral ferric and aluminum salts (free of acidity and bascicity) act better on well elutriated sludges.

If enough free acid is present in the coagulants added to digested and raw sludges to destroy bicarbonates, the free acid may disintegrate the sludge solid by liberating hydrogen sulfide. Hydrogen sulfide rapidly reacts with ferric salts to reduce them with the formation of ferric hydroxide, sulfur, ferrous sulfate and chloride and sulfuric acid.[9] In making ferric and aluminum salts of varying acidity I learned that if any of these acid salts develop hydrogen sulfide odors upon stirring them into the sludges, the floc formation was always visibly finer and filtration definitely slower, even though bicarbonates were destroyed. An overdose of acid shows this effect more readily on elutriated sludges because the bicarbonates are largely absent.

Assertions made that the removal of fine or other colloids by elutriation is largely responsible for savings in coagulant have never been given my serious consideration simply because they have been made without supplying scientific evidence. In my early work on this subject this question arose and was thoroughly investigated: namely,

1. By washing sludges without removing colloids, *i.e.* by dialysis, almost identical savings in coagulant were produced.[2]
2. By washing out colloids while *increasing* the coagulant demand of sludges, *i.e.* by washing the sludge with solutions containing higher ammoniacal bicarbonate concentrations than the sludge.
3. By concentration of most of the fine suspended solids in the elutriate through centrifuging it has been found that when the elutriate assay in ammoniacal bicarbonates is identical with the sludge moisture containing the coarser solids, both the fine and coarse solids behave in approximately the same manner toward coagulants.
4. By dialysis of normal sludge liquor or elutriate its chemical behavior toward coagulants can be materially changed. This follows from Items 1 and 2 above.

5. Counter-current elutriation in two tanks by Equations (4) and (7), and using about 7.4 volumes of pure water to 1 of sludge moisture, will leave the same fraction of ammoniacal bicarbonates as will the use of 8.5 times as much water (63 volumes) by single-stage elutriation according to Equations (1) and (5). This will result in about the same coagulant saving although more suspended matter is removed by using the greater volume of water.

6. In practice, elutriated sludges occasionally contain more solids, colloidal and otherwise, than do the sludges going to elutriation and yet they require materially less coagulant. At Baltimore the sludge going to elutriation frequently contains 6 per cent solids, whereas the elutriated sludges may contain twice this percentage. In some installations elutriated sludges have to be diluted because it is difficult to stir coagulant into them.

In sludge conditioning and filtration it is illogical to assume that the *immediate* cause of cloth blinding is finely dispersed colloids. Such colloids readily pass through all commercial filter mediums and even through paper. Without coagulation the coarser solids, settleable and suspended, and mostly of flocculated, gelatinous structure and internal colloidal nature, are first intercepted by the filter medium. Under pressure they compact to a gelatinous continuum, thus progressively intercepting the finer particles until the gelatinous blanket becomes impervious to colloidal sols and the far finer water molecules. We term this *cloth blinding.*

In coagulating and filtering sludges one is therefore primarily interested in further coarsening or curdling the larger natural sludge floccules, in order that they will not lose their more rigid identity under filtration pressure. The resulting filter cake has a matted and more open pore space structure. During coagulation some of the finer colloids will flocculate and become attached to the larger aggregates. Complete coagulation produces the most rigid coagulae and most porous cake structure. Partial coagulation results in less of the curdled aggregates being present. In all cases with commercial filter mediums the filtrate, at the beginning of cake formation, contains copious amounts of suspended fine and coarse colloids, which pass through the filter medium.

Certainly one can render coagulation of the natural sludge floccules more difficult by beating the natural floccules finer before coagulation. The same effect can be produced by beating up the coagulated complexes after coagulation, as Keefer and Kratz have ably shown.[5] Doing this with a sludge before and after elutriation may change filtration time but it doesn't necessarily change the relative coagulant dosages. These still remain roughly proportionate to the amount of ammoniacal bicarbonates in the sludge before and after elutriation, provided one uses the same sludge for making comparisons.

Undoubtedly the removal of some suspended matter by elutriation can save coagulant by making slightly less daily solids to handle, but this doesn't necessarily change the relationship between dose and solids remaining in the sludge.

On the evidence produced it may safely be assumed that if the removal of fine colloids is helpful in elutriation, the aid comes principally from the associated removal of imbibed or absorbed ammoniacal and other bicarbonates along with the fine colloids. Dialysis proves this. If as high as 1 per cent of the total sludge solids as finely dispersed matter, and 70 per cent of the bicarbonates, are removed by normal elutriation and 70 per cent coagulant saved, isn't it more logical to correlate the coagulant saving to the similar bicarbonate removal than to the removal of a very small fraction of the solids?

Colloid chemistry teaches us that truly fine colloids in very pure water can be flocculated with minute quantities of trivalent coagulants. It likewise teaches us that the relationship between these colloids and their affinity for coagulants cannot be expressed stoichiometrically. The fact that some solids are too fine to settle out during the normal process of elutriation doesn't add any mystery to their behavior towards coagulants.

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THE USE OF SODIUM AZIDE IN THE WINKLER METHOD FOR THE DETERMINATION OF DISSOLVED OXYGEN

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The triazo group (as phenyl azide, $C_6H_5N_3$) was discovered by Griess in 1866.[1] Hydrazoic acid (HN_3) was discovered by Curtius in 1890,[2] and its sodium salt (NaN_3) synthesized from inorganic materials two years later.[3] This curious group has ever intrigued the imagination of chemists. In 1934 L. F. Audrieth[4] published a review of the chemistry of the azide radical, listing a bibliography of 279 references.

The triad itself may be regarded as having either a ring[5] or a chain[6] structure—possibly tautomeric. United with hydrogen it has been variously called azoimide, hydronitric acid, or hydrazoic acid. The triazo group resembles the halogens in some properties, in others it may be likened to the ($-NO_3$) group. The triazo group is easily decomposed by heat and also to a lesser degree by such agents as ultra violet light[7] or vacuum.[8] While the azides are sometimes explosive, the thermal decomposition of some can be so well controlled as to recommend them as a source of pure nitrogen,[9] or as a basis for atomic weight determinations.[10]

In an acid medium the triazo radical reacts quantitatively with the nitrites[11, 12, 13] according to the equation:

$$HNO_2 + HN_3 \rightarrow N_2O + N_2 + H_2O.$$

The first application of this reaction to eliminating nitrites, in the determination of dissolved oxygen by the Winkler method, seems to have been made by Alsterberg in 1925.[14] In 1938 there appeared in this country a translation, from the German, of an article by H. J. Brandt[15] in which he recommends its use. These men evidently employed the sodium azide in connection with the alkaline iodide Winkler reagent; and the latter shows data to indicate that some interval should be allowed, following the last Winkler reagent, before the titration is made.

Ruchhoft and associates, however, recommend a technique with the azide patterned after the permanganate technique of the Rideal-Stewart modification.[16] They start by adding sulfuric acid, followed by 2 per cent sodium azide solution. They save a step, from the Rideal-Stewart modification, in that no reagent is added to destroy the excess of azide (as is necessary with the permanganate); and after waiting 10 minutes they proceed with the usual Winkler reagents. As in the Rideal-Stewart modification, a larger dose of the alkaline iodide reagent is required, on account of the acid which is employed at first.

Fortunately in most cases it is unnecessary to deviate from the straight Winkler procedure. B.O.D. bottles out of the 20° incubator sometimes require a modified method for D.O., when the initials did not, and then the Rideal-Stewart modification is usually used, but this procedure is not simple enough for use by non-technical workers in the field. Likewise, the azide modification proposed by Ruchhoft is unsuitable for unskilled samplers, as it requires the addition of a definite quantity of concentrated acid, then sodium azide solution, after which the sample must stand for a period of 10 minutes before the alkaline iodide is added. In the original Alsterberg modification, apparently the azide was added with the alkaline iodide, and if this were possible it would considerably simplify the technique and make it practicable for the non-technical sampler. Experiments were therefore undertaken to determine if sodium azide should be used as a pre-Winkler procedure, or if it may be used just as well as an ingredient of the alkaline iodide Winkler reagent.

The plan of the work was to take a supply of aerated river water, siphon out a number of 250-cc. bottles of this water, and treat various groups of these samples by the several procedures that have been discussed. All samples were titrated for dissolved oxygen, and the results averaged to give the data shown in Table I. In some of the runs, as indicated in the table, nitrite was added to the river water.

Table I.—*Dissolved Oxygen by Winkler Method and Modifications*

Run	Nitrite Nitrogen P.p.m.	Dissolved Oxygen, P.p.m., As Determined,				
		Winkler	Rideal-Stewart	Ruchhoft	NaN_3 in Alk. Iod.	NaN_3 Added Between Last 2 Winkler Reagents
1	0.240		7.66	7.93	7.86	7.86
2	0.500*	8.25	7.59		7.73	
3	0.286*	8.82	8.23	8.42	8.43	
4	0.214	8.57		8.42	8.42	
5	0.139	8.87	8.55	8.75	8.80	
6	0.546*	8.83	8.00	8.23	8.25	
7	0.625*	8.67	7.70	7.83	7.90	
8	0.988*	9.30	7.58	7.75	7.80	
All but 1	0.491	8.76			8.19	
All but 2	0.434			8.19	8.21	
All but 1, 2, 4	0.517	8.90	8.01	8.20	8.24	

* Nitrite added.

Results by the Winkler method were definitely higher than by the modified methods. It is, perhaps, surprising that the error in the D.O. determination by the straight Winkler method is no larger on the average than about 0.2 p.p.m. of D.O., with contents of nitrite nitrogen up to around the same magnitude, when the tendency for the starch-iodine color to return is considered. The method is seen to be quite unreliable, of course, with the higher nitrite contents.

Employing the azide as an ingredient of the alkaline iodide Winkler reagent gave results which average slightly higher than the Ruchhoft method, but the difference is within the experimental error. The Rideal-Stewart modification gave the lowest D.O. values, which averaged about 0.2 p.p.m. lower than those obtained by the azide methods.

Employing the azide as an ingredient of the alkaline iodide reagent seems, therefore, to give satisfactory results. As a method it should recommend itself for simplicity. The only difference from the straight Winkler procedure is in the fact that the alkaline iodide reagent must contain enough sodium azide to unite with the nitrite nitrogen in equimolecular proportions.

If 2.0 c.c. doses of the alkaline iodide are used, 8.0 gm. per l. of the sodium azide in the reagent will provide the same amount of the salt in a 250 c.c. sample bottle as used by Ruchhoft. This is sufficient, theoretically, for 13.8 p.p.m. of nitrite nitrogen in the sample. In making up the alkaline iodide reagent to contain the NaN_3, the latter should be dissolved in a separate small quantity of distilled water, and filtered if necessary, before adding to the already dissolved and cooled mixture of hydroxide and iodide. Care should be exercised to avoid local heating, by stirring and cooling while adding the azide solution, and diluting up to the mark. It may also be advisable to make up this reagent in small quantities which will be used up within a short time, and to keep it in brown glass bottles.

CONCLUSION

1. The use of sodium azide as an ingredient of the alkaline iodide Winkler reagent is recommended in the determination of dissolved oxygen in samples which contain nitrites in objectionable amounts.

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Discussion by E. Hurwitz

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Comparisons have been made of the modification of the Alsterberg method, as suggested by Ruchhoft, with the Winkler and Rideal-Stewart methods. Rapid sand filter effluents and high-rate filter effluents containing varying amounts of nitrite were used. Results are shown in Table I. The Ruchhoft modification gave results consistently lower than the Winkler and higher than the Rideal-Stewart. Since the former is always high in the presence of nitrites and the latter low in proportion to the amount of excess oxalate added, the Ruchhoft modification would seem to be more nearly correct. Comparisons were later made of the Ruchhoft modification and the Alsterberg (azide) method which was revived by Barnett (Table II). Activated sludge effluents from the Southwest Sewage Treatment Works were used. The azide solution was made up according to Ruchhoft's specifications. For the Alster-

TABLE I.—*The Sanitary District of Chicago. Main Laboratory*
Aug., 1938

Dissolved Oxygen in Effluents Containing Nitrites. Alsterberg (Azide) Method—Ruchhoft Modification

Parts per Million

Jenks Filter Eff.				Halvorson Filter Eff.				Rapid Sand Filter Eff.			
Dissolved Oxygen			Nitrite N	Dissolved Oxygen			Nitrite N	Dissolved Oxygen			Nitrite N
Winkler	Rideal-S.	Azide		Winkler	Rideal-S.	Azide		Winkler	Rideal-S.	Azide	
6.3*	5.2	5.55	0.8	5.4	3.7	3.9	1.0	6.6	5.2	5.4	1.0
5.5	5.0	5.2	1.0	4.1*	3.75	4.0	0.4	6.55	6.0	6.0	1.0
5.5	5.0	5.25	0.6	5.65	5.05	5.35	0.7	6.65*	6.0	6.25	1.4
5.15	4.95	5.1	0.6	5.05	4.65	5.0	0.6	6.7*	5.65	5.95	1.2
6.95	6.4	6.75	0.8	7.05*	6.25	6.6	0.8	7.85	6.8	7.15	1.4
6.6*	5.45	5.7	0.9	6.4	5.5	5.9	0.9	6.4*	5.0	5.3	1.4
6.5*	6.0	6.1	0.5	6.55	6.2	6.35	0.4	5.65	5.0	5.15	0.8
6.8	6.3	6.5	0.5	6.85	6.65	6.85	0.5	8.25	7.45	7.5	1.0
8.15*	6.65	6.95	0.6	6.8	6.4	6.7	0.5	8.3	7.55*	7.75	1.6
7.45	6.7*	7.0	0.7	6.15	5.6*	6.05	0.45	8.0*	7.15	7.3	1.8
7.45	6.35	6.55	0.7	6.35	5.75	6.2	0.5	7.75	7.05	7.35	1.0
6.7*	6.15	6.4	0.7	6.2*	5.65	6.0	0.4	7.5	6.9	7.25	0.8
5.95	5.45	5.6	0.6	4.6	4.2	4.5	0.45	6.45	5.8	6.05	0.9
7.3*	6.55	6.65	0.6	4.5	4.25	4.4	0.5	6.65*	6.1*	6.3	0.8
7.75	7.1*	7.35*	0.4	3.25*	3.0*	3.2	0.3	8.1*	7.3	7.55	2.5
6.3*	5.75	5.95	0.8	0.55	0.25	0.3	0.6	7.85	7.1*	7.4	1.8
6.6	5.85	6.1	0.8	5.4*	5.0	5.25	0.5	7.25*	6.9	7.1*	0.6
6.25*	5.9	6.05	0.3	4.8	4.5*	4.8	0.3	6.55	6.2	6.3	0.5
7.45	6.95	7.1	0.8	4.9*	4.65	4.95	0.8	7.85	7.4	7.55	1.2

* Indicates variation of more than 0.1 between duplicates.

TABLE II.—*The Sanitary District of Chicago. Main Laboratory*

Dissolved Oxygen in Effluents Containing Nitrites
Comparison Alsterberg and Ruchhoft Modification
Parts per Million

Date 1939	Winkler Method	Azide Method: Ruchhoft Modification	Azide Method: Alsterberg (Azide) Method	Nitrite N
July 6	11.0	6.3	6.3	4.0
		6.3	6.2	
7	9.6	5.8	5.7	1.2
			5.7	
8	11.6	6.2	6.2	1.8
9	13.6	6.3	6.4	5.5
		6.4	6.4	
10	11.6	5.7	5.6	4.0
		5.7	5.6	
11	6.4	5.9	5.7	0.8
12	5.9	5.7	5.7	0.4
13	6.1	6.0	6.0	0.15
16	11.0	6.8	6.6	2.5
19	12.4	6.5	6.6	3.0
20	10.6	6.0	6.0	3.0

berg modification 2 grams of azide were dissolved directly in 100 c.c. of alkaline-KI solution. The solution is complete but occasional shaking and an hour or two contact is required. It is probably better and easier to dissolve the azide in part of the water required for the alkaline-KI and add the azide solution to the alkaline-KI. One c.c. of alkaline-KI-azide solution was used. Final acidification was increased to 1½ c.c. conc. H_2SO_4. Ten minutes was allowed after acidification before titrating.

The differences in the D.O. found by the two modifications are well within the limits of error of the titration. Within the limits of the tests the amount of nitrite present did not influence the results. The titrations by the Winkler method are shown merely to demonstrate the efficacy of azide in eliminating error due to nitrites.

Ruchhoft and Brandt state that at least ten minutes should be allowed after acidification. In order to use this method in plant control it is desirable that no reaction time be required. The results shown in Table III indicate that for all practical purposes this reaction time can be eliminated. In fact, the difference in D.O. found when titrating immediately after acidification and after varying time intervals up to ten minutes was never more than 0.1 which is within limits of error of titration. Amounts of nitrite up to 25 p.p.m. did not affect the results. With 50 p.p.m. there is a slight lag. However only in exceptional cases will such excessive amounts of nitrite be encountered. The results of these tests indicate that the reaction is immediate and that no time need be allowed for reaction after acidification.

TABLE III.—*The Sanitary District of Chicago. Main Laboratory*

Dissolved Oxygen in Effluents Containing Nitrite
Alsterberg (Azide) Method
Results in Parts per Million
Reaction Time after Acidification

Nitrite (N)	12 p.p.m.					6 p.p.m.					3 p.p.m.					1½ p.p.m.				
Reaction Period,[1] min.	0	2	5	7	10	0	2	5	7	10	0	2	5	7	10	0	2	5	7	10
Azide [2]					8.2					8.5					8.6					8.8
Azide—No. 2 [3]	8.2	8.3	8.3	8.3	8.2	8.6	8.6	8.6	8.6	8.6	8.7	8.7	8.6	8.6	8.6	8.7	8.8	8.7	8.8	8.8
Rideal-Stewart					8.3					8.4					8.5					8.6
Winkler	24.8					16.1					13.4					9.8				
	50 p.p.m.					25 p.p.m.					4 p.p.m.					2 p.p.m.				
Azide [2]					8.3					8.3										
Azide—No. 2 [3]	9.9	8.9	8.5	8.5	8.5	8.4	8.4	8.4	8.4	8.4	5.9	6.0	5.9	6.0	6.0	6.1	6.2	6.2	6.2	6.2
Rideal-Stewart					7.8					8.2										
Winkler	32.6					26.2					10.0					10.3				

[1] Time elapsed between acidification and titration.
[2] Azide used according to C. C. R.
[3] Azide used according to Alsterberg.
[4] Activated sludge eff. others, tap water plus added nitrate.

The alkaline-KI-azide solution made up as described above was stable for at least three weeks. Since these tests were made we have found that one gram of sodium azide per one hundred c.c. of alkaline-KI is ample to care for nitrites in the amounts which may be expected in any normal sewage plant effluent or stream sample.

We are now preparing all our alkaline-KI-azide solution as described and we have adopted this procedure for determining D.O. for stream pollution studies, control of D.O. in aeration tanks at the Southwest Sewage Treatment Works and industrial waste studies. In fact, we have replaced the alkaline-KI for the alkaline-KI-azide solution for all D.O. and B.O.D. determinations.

Plant Operation

APPLICATION OF SEWERAGE FINANCE METHODS *

By Francis S. Friel

Consulting Engineer, Philadelphia, Pa.

Last year, George F. Baer Appel, a member of the law firm of Townsend, Elliott and Munson, delivered a paper before this Association entitled "Some of the Legal Aspects of Financing Sewerage Projects in Pennsylvania Municipalities." (*This Journal*, Sept., 1938.) My paper is, in effect, a continuation of Mr. Appel's discussion. In order that it may be complete, I will first recite the methods which are legal; and then dwell upon the practical application of these methods. Mr. Appel's paper was very complete and covered thoroughly the legality of financing sewerage projects. He outlined four methods, which I quote as follows:

"*Method I.*—The first method is the issuance by the municipality of general obligation bonds, the proceeds of which are to pay all the costs of constructing a complete sewer system, including the branch sewers as well as the pumping stations, sewage treatment plant and outfall sewers. The ability of a municipality to insure bonds for this purpose is dependent upon its borrowing capacity. A municipality may incur a debt of 2 per cent of its assessed valuation of property for taxing purposes without obtaining the consent of the electors, and up to 7 per cent with the consent of the electors. These bonds are paid off out of taxes levied on all property owners in the municipality.

Method II.—The next method of financing sewerage projects is by assessing the cost against the property owners abutting the sewers. This method is seldom, if ever, used exclusively, since part of every sewer system is non-assessable, and it is usually necessary to supplement the assessments with the proceeds of general obligation bonds. There are two ways of assessing the cost of part of a sewer system against the abutting properties. One is by benefits, and the other by the so-called front foot rule. The latter has become the more popular and is the less cumbersome. Where a municipality cannot afford to issue general obligation bonds for an entire sewerage project, it often can issue enough to provide funds for the non-assessable costs, such as the sewage treatment plant, the outfall sewer and pumping stations, allowing the cost of the collection system proper, or so-called branch sewers, to be paid by the properties abutting on and benefited by the sewers. It is customary to pay the contractor in assessment bonds which bear an interest rate of 5½ per cent. These bonds are redeemed when the abutting property owners pay their assessments; and it is further customary to permit the property owners to pay their assessments over an extended period of five or six years. An interest rate of 6 per cent on the unpaid balance is charged to the property owners.

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* Presented at the Thirteenth Annual Meeting of the Pennsylvania Sewage Works Association, State College, June 27, 1939.

Method III.—In 1935, the Legislature of Pennsylvania passed an Act known as the "Municipal Authorities Act of 1935." For all practical purposes, an Authority is substantially the same as a corporation, and the act therefore authorizes the formation by a municipality of a corporation which is separate and distinct from the municipality itself. One of the purposes for which a Municipal Authority may be organized is for constructing, improving, maintaining and operating sewers, sewer systems, and sewage treatment works. Among the powers granted to the Municipal Authority are to borrow money and to make and issue bonds of the Authority, and for that purpose to enter into a deed of trust or indenture in which the revenues received by the Authority are pledged as security for the bonds.

Thus, if a municipality is unable to finance a sewerage system by either general obligation bonds or assessment bonds, it may organize a Municipal Authority which has the power to construct a sewerage system, sewage treatment plant, and pumping stations, and to charge the property owners for the use of these sewers, and to finance the construction by the issuance of bonds secured by sewer rentals.

Method IV.—The most recent method of financing sewerage projects is by the issuance of "Non-debt Revenue Sewer Bonds." The power to issue these bonds was given to Boroughs by the Act of May 7th, 1937—P.L. 582. In many respects, this method is similar to that of creating an Authority. Both provide for indentures or deeds of trust, and the bonds do not pledge the credit of the municipality, nor become a lien upon the properties, but are secured solely by the revenues from the sewer system. Under this method, the revenues are derived from annual rentals or charges which boroughs are authorized to impose by the Act of May 14th, 1937—P.L. 630, which amends the Act of July 18th, 1935—P.L. 1280. The annual sewer rentals or charges which may be imposed may be sufficient to meet any or all of the following classes of expense:

(*a*) The amount expended annually by the municipality in the operation, maintenance, repair, alteration, inspection, depreciation, or other expense in relation to such sewer or sewage treatment works;

(*b*) Such annual amount as may be necessary to provide for the amortization of the Non-debt Revenue Bonds issued by the municipality in the construction or the acquisition of such sewer, sewerage system, or sewage treatment works and interest thereon, in order that said improvements may become self-liquidating;

(*c*) Sufficient to establish a margin of safety of ten per centum.

The annual rental or charge imposed by the municipality is made a lien on the property served and, as such, the lien may be filed in the office of the prothonotary and collected in the manner provided by law for the filing and collection of municipal liens. In other words, these annual rentals or charges are thus placed in the same category as assessments and other municipal claims." Since Mr. Appel delivered his paper last year, the Court of Quarter Sessions of Schuylkill County, in the Frackville Sewerage Company vs. the Borough of Frackville case, held that the Non-debt Revenue Sewer Bond Act is constitutional. The case of Lighton *et al. vs.* Abington Township *et al.* was argued in the Montgomery County Court, and on April 21, 1939, this Court held that the Non-debt Revenue Sewer Bond Act is constitutional. The Abington Township case was appealed to the Supreme Court of Pennsylvania and argued on May 23, 1939. (To date an opinion has not been handed down.)

Practical Application of Sewerage Finance Methods

General Obligation and Sewer Assessment Bonds.—You are familiar with the issuance of general obligation bonds to raise funds with which to pay the cost of constructing a sewer system. A municipality usually does not have sufficient borrowing capacity to issue general obligation bonds to finance the construction of a complete sewer system, sewage treatment works, and pumping stations, and it becomes necessary to resort to a combination of general obligation and sewer assessment bond issues. The funds derived from the general obligation bonds are used to finance the cost of the sewage treatment plant, pumping stations, outfall sewers and other non-assessable portions of a system, while the funds derived from sewer assessment bonds are used to finance the construction of the branch sewer lines which are assessable. I understand that townships of the first class in the Commonwealth of Pennsylvania cannot issue sewer assessment bonds. I shall first dwell upon the practical application of financing a system in the Commonwealth of Pennsylvania with a combination of general obligation and sewer assessment bonds.

There are several important preliminary steps to be taken in the procedure of establishing a municipal sewer system. It is necessary first to make a sanitary survey and to prepare a comprehensive plan of the sewer system and of the methods of disposal. The second step is to introduce a local campaign to educate the public in the necessity of a sanitary sewer system, in order to obtain their support. At this point in the procedure, a recognized attorney on matters pertaining to bond issues should be employed. It is usually advantageous to arrange for the employment of a bond attorney to assist the local solicitor. I wish to stress the importance of proper legal advice in order to avoid many pitfalls which may later arise.

With Federal aid available through P.W.A. grants and through W.P.A. assistance, it is the common practice to construct municipal sewer systems today with some form of Federal assistance and such aid should be sought in order to minimize local cost. It will not be necessary for the bond attorney to render service other than that of an advisory nature prior to the submission of an application for Federal aid.

However, the bond attorney should prepare the election ordinance and the election notice and should be responsible for all subsequent ordinances covering construction.

It is very important that a sewer assessment ordinance be complete and carefully prepared. This ordinance should contain a detailed description of the location of each individual sewer line; a description of all rights of way for the sewer lines; a description of sites for pumping stations and the sewage treatment plant; and the authorization for the municipality to make and enter into contracts on the part of the municipality for the construction work. The ordinance should further provide that the cost and expenses of the collection system be paid by the assessment of the amount of such costs as a tax upon the properties abutting upon the sewers, by the front foot rule, if such method is adopted. In the case of corner lots, the ordinance should set forth the method of assessing such properties where sewers are constructed on both sides of the corner lots. It is customary to allow a 100-foot exemption on the long side. It is necessary to state further in the ordinance that, immediately upon the completion of the sewer system, the engineers shall ascertain the exact cost of that portion of the system which is assessable against the adjoining properties. The front foot assessment is established by dividing the total cost of constructing the assessable portion of the system, plus overheads and interest during construction, by the assessable front footage. The figure thus determined is used as the unit cost per front foot for billing. The first payments made by the property owners are used to pay the interest on the bonds during the construction period.

A section of the ordinance is devoted to the payment of assessment bills, and it usually states that the proceeds from the assessments are to be retained by the city or borough treasurer in a sinking fund to be applied in payment of the principal, interest and state tax, if any, on the assessment bonds. Should an owner of a property against which an assessment is made neglect to pay the assessment within thirty days after it becomes due, the municipality should file a claim, together with a penalty of five percent plus the interest on the principal, and it is the duty of the city or borough solicitor to file a lien against the property.

A property owner should have the privilege of paying his assessment on the partial payment plan, by making an initial installment of one-sixth of the amount of the assessment plus an additional sum of two or three dollars to cover the necessary legal expense. The remaining five installments should be paid annually, plus interest at six percent per annum on the unpaid balance. In case of default of a property owner in the payment of an installment for a period of sixty days after it becomes due, the entire balance of the assessment and the accrued interest thereon should then become due and payable. It again becomes the duty of the treasurer of the municipality to notify the solicitor of such default, and the solicitor is charged with the responsibility of collecting the sum due, under the general law relating to the collection of municipal claims.

Finally, the sewer ordinance should contain the exact form of the bonds to be issued. This type of bond is usually described as a "Sewer Assessment Bond," and the bonds are issued in denominations of five hundred dollars. The bonds bear an interest rate of 5½ per cent per annum, and the interest is payable without deduction for any tax or taxes, except succession or inheritance tax. The first interest payment on the bonds, which consists of the interest from the date a bond is issued until the date of such payment, is usually made within thirty days after the first installment on the property assessments is due; and the interest is paid semi-annually thereafter each year, until the bonds are called for redemption.

The principal, interest, and state tax on sewer assessment bonds are based solely and rest alone for security on the assessments made and levied under the ordinance, and the municipality is made liable only for the amount collected in such assessments. As often as there is five hundred dollars in the hands of the municipality's treasurer from the assessments, in excess of the interest and state tax requirements for one year on the bonds then outstanding, the treasurer shall call in the bonds for payment in their numerical order. The bonds are registered in a registry book kept by the treasurer showing the date of the issue of the bond, the amount of the bond, and the name of the person to whom it was issued. The bonds may be transferred at any time and, when the municipal treasurer is notified, it is his responsibilty to make the proper entry of the transfer.

Sewer assessment bonds must be issued and negotiated by a municipality at not less than par, and the proceeds from the sale of the bonds shall apply solely to the payment of the cost of the sewer system constructed; or the bonds may be delivered to the contractor in payment for his work, in which case they shall be delivered at not less than par. When this type of bond is delivered to the contractor in part payment for his work, he usually arranges with a broker to purchase the issue in its entirety. The broker in turn sells the bonds to individual customers. The price paid by the broker to the contractor depends, to a large degree, upon the financial standing of the municipality. It usually ranges from about 96 to par. The contractor, when bidding, takes up the discount, if any, by increasing the cost of the construction work performed so that he will be assured of receiving full payment in cash.

Generally speaking, on P.W.A. projects, the contractor is paid 45 per cent in cash and the remaining 55 per cent in bonds, the 45 per cent representing the Federal grant. On some projects constructed with P.W.A. aid, the contractor on the sewers has been paid practically the entire amount in sewer assessment bonds and the 45 per cent Federal grant has been used to pay for the non-assessable portions of the system and the cost of constructing the outfall sewers and sewage treatment works.

In some quarters, fears have been expressed regarding the delinquencies in sewer assessment collections. From recent experience in one Pennsylvania municipality, I find, out of a total of 956 properties assessed, there were 787 property owners, or 82.5 per cent, who paid their assessments immediately. Eighty-three property owners elected to use the partial payment plan, and 86 ignored payments altogether. In a period of three years—from 1936 to 1939—88.5 per cent of the total amount assessed had been paid.

It would be well to point out the pitfalls in the preparation of sewer assessment lists. In order that a sewer assessment may be properly prepared, it is necessary to make a search of the titles of the properties to ascertain the names of the property owners and also the front footage upon which the assessment is to be based. Complete plans of all assessable properties should be prepared, showing the location and size of all properties, together with the assessable frontage and the location of the sewer lines. Care should be exercised in the preparation of these plans so that their accuracy cannot be questioned. The methods of assessing irregularly shaped properties should be completely covered in the sewer assessment ordinance.

A complete municipal sewer system for a Pennsylvania municipality, with a population of 12,000, was recently completed under my direction. The sewer system proper comprised about 25 miles of lines, varying in size from 8 to 24 inches. This project was financed by the issuance of general obligation bonds and sewer assessment bonds, together with a Federal grant. The contractor was paid approximately 40 per cent in cash and 60 per cent in sewer assessment bonds. The front foot assessment in this instance was $1.80. In another project which came under my direction, for a municipality with a population of approximately two thousand people, a larger proportion of general obligation bonds was issued than in the case cited above, and in this instance the sewer assessment was $1.50 per front foot. This system was constructed with P.W.A. assistance.

The Municipal Authority and Non-Debt Revenue Sewer Bonds.—The methods utilized in arranging for the financing of a sewer system under a Municipal Authority or by the issuance of non-debt revenue sewer bonds will be practically the same. In the first instance, however, the project is handled by an authority, whereas in the latter case the work comes under the direction of the city or borough council. The preliminary steps to be taken in the procedure for the establishment of a sewer system to be financed by either of these two methods would be similar to that which I have heretofore outlined for the issuance of general obligation or sewer assessment bonds. A sewer plan must be prepared; the public educated; and a bond attorney employed. It is of great importance to employ a recognized bond attorney for all legal matters pertaining to the issuance of Authority or non-debt revenue sewer bonds.

In order to make Authority bonds or non-debt revenue sewer bonds saleable, careful engineering estimates must be prepared. These estimates must show accurate data on the cost of construction; the cost of operation; the cost of maintenance; the cost of collecting rentals; annual depreciation; and the number of houses which will be connected to the sewer system each year during the period of development. With accurate estimates covering the foregoing items, it is then possible to determine the annual rental to be charged for the sewerage service. I have heretofore stated that the annual sewer rental which may be imposed in these two cases should be sufficient to meet the costs of operation, maintenance, repair, alteration, inspection, depreciation, and amortization of the bonds and the interest thereon, together with a fund sufficient to establish a margin of safety of 10 per cent. Inasmuch as the revenue to be obtained from sewer rentals is the sole security for these types of bonds, it will be evident that great care must be exercised in the preparation of the preliminary estimates.

The data for several bond issues of this type have been worked out under my direction, and I find a convenient form of tabulation for presenting the entire financial picture would consist of a series of horizontal columns with the following captions:

1—Year
2—Number of houses connected to system
3—Annual rental per house
4—Total amount collected from annual rental
5—Annual operation cost
6—Annual maintenance cost
7—Annual depreciation
8—Annual cost of collection

Columns 9, 10, 11, 12 and 13 would show a computation on the bond issue, and would be in the following sequence.

9—Total amount required for bond service
10—Amount earmarked for amortization of bonds
11—Interest and state tax
12—Outstanding bonds
13—Residual in treasury at end of year
14—This column should show the total disbursements during the year
15—This column would show the surplus at the end of the year.

In setting up this financial picture with the foregoing captioned horizontal columns, the tabulation should then be completed for each successive year during the life of the bonds.

It is my opinion that this type of bond should be set up to mature serially over a period of 30 years, which is the legal limit in Pennsylvania. The bond maturities should be arranged so that the early maturities during the development period will be low, in order to counterbalance the high early interest requirements. The bond maturities plus the annual interest should be approximately the same each year throughout the life of the issue.

In order to determine the annual rental for each individual house, a system of charges should be established prior to the issuance of the bonds. If a rental is to be charged based on fixture units, it would be well to have a survey made of the fixtures in a municipality in order that such a rental could be accurately established. Careful consideration should be given to what is commonly called the " lag " in the rate the houses will be connected to the system during the development period. The "lag" has an important bearing upon the revenue to be derived to support the bond issue during the first five years. I have collected data showing the rate at which connections were made to two municipal sewer systems constructed under my direction. The curve attached hereto shows these rates. During the end of the first year, the average of the two towns shows 46 per cent of the connections had been made; at the end of the second year, 72 per cent; at the end of the third year, 90 per cent; and at the end of the fourth year, 96 per cent. In one instance, the unconnected houses, at present numbering 20 out of a total of 769, will probably not be connected to the sewer system unless pressure is brought to bear by the municipality.

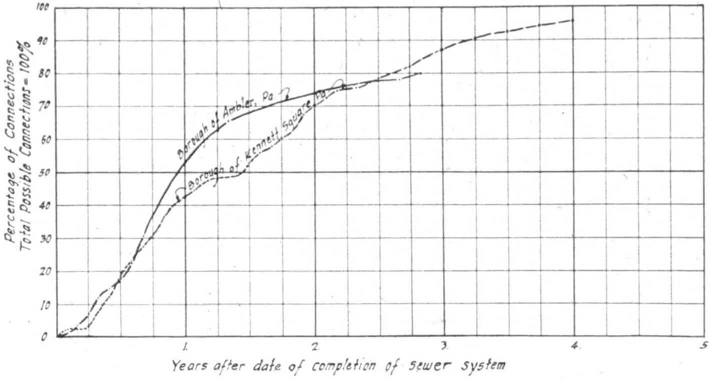

FIG. 1.—Curve showing rate of sewer connections after completion of sewer system.

An approximate figure of the annual rental to the individual householder—with the issuance of non-debt revenue sewer bonds to finance cost of construction, may be of interest. From my experience in working up several issues of this type with P.W.A. aid, I find that the annual rental would be approximately $25.00 per year for the average small municipality.

Combination of Non-Debt Revenue and Sewer Assessment Bonds.—It appears to be possible to construct a sewerage system by combining an issue of non-debt revenue sewer bonds with sewer assessment bonds. If this type of financing is employed, the annual rental would be reduced, but the property owner would be required to pay an assessment covering the cost of installing the branch sewers. I have worked out this combination of financing for several municipalities, and with a sewer assessment of $1.50 per front foot, the annual rental to the average household would be approximately $10. This is based on Federal aid with a 45 per cent P.W.A. grant.

CONCLUSION

No doubt many of you here today can point with justifiable pride to complete modern sewerage facilities in your municipalities. With the advent of Federal aid and with the growth of municipalities and the increasing needs for modern sewerage facilities, together with the various methods of financing now available in the Commonwealth of Pennsylvania, practically every municipality is in a position to construct a sewerage system. The development of a sewer system will make a municipality a safer and healthier place in which to live.

DISCUSSION OF THE PAPER BY FRANCIS S. FRIEL: "APPLICATION OF SEWERAGE FINANCE METHODS"

By E. E. Bankson

Consulting Engineer, Chester Engineers, Pittsburgh, Pa.

It has been my pleasure to review Mr. Friel's analysis in advance of today's meeting, and I am impressed that the subject is timely in its limitation to "Finance Methods" as well as its general exclusion of "Sewerage Charges or So-called Rentals"; upon which volumes have been written dealing with opinion and variation. We are indebted to Mr. Friel for a detailed analysis of this type.

After having prepared a number of bond schedules with the supporting computations of revenues and expenditures, I can well appreciate the need for caution, as stressed by Mr. Friel, and the need for the services of a bond attorney. In fact, the bonds will not sell until approved by a bond attorney and the prospect of Federal penalties, or fines, against erroneous statements, or misleading data of any report in support of a proposed bond issue, will tend to provide the caution here suggested in detail.

Regarding the four methods of financing, it has been my interest more recently to observe the strength of habit of our people when faced with the prospect of some variation from that to which they have been accustomed. As an example, most older communities have always provided sewer service from general funds and are often reluctant to make a change by the adoption of a sewer rental. Also, I find extensive aversion by public officials to the idea of property liens; as both undesirable and cumbersome or ineffective. We need only think of the long struggle for meterization of water service and the continued opposition, as represented by the first city of our land, where flat rate water service is still in vogue.

Although many states can boast of a long practice of sewerage charges or rentals, it would appear evident that the more recent opportunities of assistance from Federal finances has added greater impetus to the method of revenue bonds; beginning, in our experience, with the first R.F.C. loans and reaching a peak, perhaps, under the last P.W.A. Program. Our so-called "Non-debt Revenue Bonds," however, would seem to possess a misleading name, for the reason that a "debt" *is* thereby created. The result is a debt supported by certain revenues, instead of a debt against property or the general tax levy.

It may be pertinent to discuss a plan of revenue bonds by a municipality or an authority where a portion or all of the revenues may be provided from a general tax levy and the remainder, if any, from sewerage charges. The State Act No. 169 of May 14, 1937, P.L. 630, provides that whenever any city, etc., shall singly or jointly enter into a contract with any authority for the furnishing of sewerage service, . . . such city . . . may provide . . . for an annual rental, etc. This would appear to permit a support for revenue bonds of an authority from general taxes of a city by means of an agreement between the two.

Especially would such a program answer the rather common criticism or claim that sewerage service creates a benefit to property, as such, in contrast to the principle that usage or current service should carry the entire burden. A further complication sometimes arises where funds are expended partially for replacement or relief of sewers which also carry storm water, such as combined sewers. The service of storm water removal through such sewers is totally unrelated to many units of measure, or types of measure, now adopted for the basis of sewerage charges or rentals.

The recent study and report by the American Public Works Association, on Sewer Rentals, carries the statement of opinion that "It is impossible to distinguish between those portions of a sewer system that create widely diffused public benefit, as public health, etc., and those that yield individual benefits. . . . The public benefit cannot readily be evaluated in terms comparable with those used to evaluate individual benefits." A rather strong opinion prevails in some quarters to the effect that general taxation should carry all fixed charges, or debt service, and that the sewer rental charges should provide sufficient revenue only to cover operating costs. You may recall that the Brockton report of over forty years ago, by Dr. Herbert Snow and others, proposed a division between a general tax levy, a frontage assessment, and an annual rental. Abel Wolman and others, have more recently presented somewhat similar arguments.

If those arguments be valid, it then follows that the plan of sewer rentals sufficient to carry the entire annual burden of debt service and operating costs, including depreciation, will transfer an excessive burden onto current users, instead of requiring that property should carry a part of the burden, through the avenue of general tax levy.

Too much variation in types of rate schedules, however, already exists and it may not represent a vain hope that we now proceed toward simplification and uniformity, instead of greater complication. For instance, the comprehensive report of Childs and Schroepfer, for the Metropolitan Drainage Commission of Minneapolis and St. Paul, regarding "Sewer Rental Laws and Charges" in vogue before 1932, recited 18 different methods or types of charges in 26 different states. The recent study of American Public Works Association reduced the types to 6 principal bases; of which the water sales or the plumbing fixtures constituted the basis of rates in 70 per cent of the 100 cities selected for study, in 24 different states. The writer is prone to consider a two-part rate schedule for greater equity, by a combination of rooms and water sales, or lot frontage and water sales, for the reason that either alone may create an injustice for certain cases; as does most any taxing method.

My opinion is in accord with Mr. Friel's that early bond maturities should be held to lower amounts in order to counter-balance the early higher interest requirements, to the end that the combined or total annual burden from debt service may either remain uniform throughout the period of bond retirement or run parallel with the estimated revenues. My statement, however, refers to the entire period of bond retirement instead of only for the "development period." Such a plan, however, is found to conflict with the Ohio Law, for instance, and with much common practice in Pennsylvania, of bond retirement in equal annual amounts. In fact our recent Stream Pollution Act provides for bond retirements by equal annual payments. My criticism of this feature brought response from the office of the Attorney General that other State Acts of 1937, relating to such bond issues, do not make a requirement of equal annual payments.

Both an interesting and troublesome phase of these "Practical Applications" is that the sewer rental charges or rates must be gradually decreased throughout the bond retirement period for those cases of equal annual payments. Sinking fund plus interest payments start out as a maximum for the first year and approach zero for the last year of a bond retirement period. With a limitation of rental revenues to within a 10 per cent margin it follows that an equal annual retirement plan would involve a gradual reduction in the sewer rental charges until the revenues therefrom could provide for only the operating expenses during the period of plant existence beyond the completion of bond retirements. This fact offers sound argument for the suggested plan of uniform annual burden through a proper counterbalance between high early interest payments and low early maturities, in order to maintain a uniform rate schedule, or tax levy, throughout the bond retirement period, or life of the bonds. This provision will also avoid initial rates which are impossibly high.

The opinion of Mr. Friel that the bond retirement should be completed within a period of less than 30 years, raises the question as to why we should unduly burden the present generation with the complete payment for sewer facilities that possess a service life extending forward for several generations—such as well constructed sewers. The life of a treatment plant may fall within the shorter period but that for sewers is quite a different matter. I believe that New York City, and some others, has or have established a practice of bond issues up to 50 years or so, for facilities of longer life.

At this point may also be mentioned the fallacy of providing current revenues sufficient to cover both the bond retirements, or sinking fund, and secondly for an annual depreciation loss. It appears vividly clear to the writer that the provision for both, concurrently, produces a duplication of burden on the present generation and should not be encouraged.

In conclusion, therefore, my mind is open and receptive to a clarification or crystallization for all of these and other questions. The constitutionality of non-debt revenue sewer bonds appears almost established, though we now await a decree from our State Supreme Court. With full legality established, it appears possible that such bonds will find a greater demand from available capital, and become more popular with the borrower, or with the people.

General Discussion

Mr. Bankson: In Pittsburgh they are faced with a question of two cases of sewer rentals outside the municipality, and no charges in the municipality. I wondered if there were any pitfalls there. Has any one had any experience on that?

Mr. Friel: I think the only pitfall you may have is the fact you will have people outside the borough who will be disappointed that they are not getting free service. Other than that, I don't think there are any legal impediments in the procedure.

Commenting on Mr. Bankson's discussion, as I size up the picture, the non-debt revenue bonds will not become very popular when issued alone, for the simple reason that the sewer rental will be so high it will be very discouraging to a property owner. If you will recall, in the paper I said the sewer rental would be $25 for the average house, with a 45 per cent P.W.A. grant. Without a P.W.A. grant, it means that the sewer rental will be up around $40 or more, which is not practical.

Another thing, too, I wish to comment on, so far as the life of these bonds is concerned. I quite agree it would be well to extend the bonds over a period greater than 30 years, but, as I understand the law in the State of Pennsylvania, 30 years is the limit. Isn't that correct?

Mr. Bankson: Yes. I am really discussing the merits of the laws.

Mr. Friel: I know that down in Maryland we have a project just outside of Baltimore, Baltimore County, and some of the sewer bond issues run 40 years, and some 50 years.

It may be well to comment on their methods. Instead of assessing the cost of the sewer and then charging a rental, they charge a rental each year in sufficient amount to pay the assessment, which is amortized by this rental over a period of 30 or 40 years, plus the operation cost. It is the same thing in principle as the non-debt revenue bonds.

So far as the setting up of both a sinking fund and a depreciation fund to provide sufficient funds in the rental for depreciation, I quite agree that shouldn't be done. The two funds are for the same purpose. However, the bond attorneys want us to set up both funds, and, of course, it makes a little bit higher rental.

Mr. R. L. Phillips: One or two things occur to me that I think might be of interest.

Very few people in the small municipalities seem to realize the true meaning of 2 per cent bonding power by councilmanic action. The Council has the power to bond up to 2 per cent regardless of the fact that a 4 or 5 per cent debt may have been incurred previously by action of the electors. By this I mean that although the municipality may have a debt of 5 per cent of its assessed valuation, the Council has the power to incur an additional 2 per cent by their action.

I do not at all agree with Mr. Bankson about the desirability of extending the period over which bonds are amortized, and am very much of the opinion that the "pay as you go" plan is desirable. I believe that our gifts to posterity are more than offset by our inheritances from the past. The future brings its own troubles and our children will have plenty to pay for without saddling them with any more debt than necessary in order that the cost of present public works may be scientifically apportioned over the entire life of the improvement.

I have also been surprised to learn that comparatively few smaller municipalities have taken advantage of their opportunity to simplify improvement legislation by the passage of comprehensive ordinances defining the duties of the various city officials in connection with the financing and carrying on of the work on street paving, sewers, sewage treatment plant construction, and similar enterprises. A carefully written comprehensive ordinance outlining proper methods of procedure and defining the duties of the various city officials in connection with various types of improvement makes it possible to simplify the necessary legislation by the passage of a very brief ordinance, perhaps only one or two paragraphs long, when the actual improvement is contemplated. This, of course, aids in financing as it greatly decreases advertising costs.

Mr. L. P. Blum (Pittsburgh, Pa.): Curiously enough, I am in agreement with Mr. Bankson. Last night we had quite a disagreement.

I was just wondering, when listening to Mr. Friel, if it was a proper subject to introduce the idea that Mr. Bankson did introduce.

May I say something reminiscently. As a young man I worked on the intercepting sewer in the Schuylkill watershed. It was built in 1898. We worked on branches from 1901 to 1906 or 1907, when the entire community was sewered under this assessment plan and bond issues. Those bonds were amortized, the last of them possibly in 1928. I am sure that those sewers today are just as useful to the community as they were when they were built. There was little difficulty in getting people to use the sewers, they wanted them, and there was no difficulty in securing the connections.

Now, why should the community of Roxborough, and others, have the enjoyment of those sewers without cost from 1928 on until the end of their life, which may be 100 years? There is not one of us here who has constructed sewers who doesn't know it is perfectly possible that every one of our sewers ought to last 50 years anyhow, or longer.

If we amortize our bonds in 50 years for such permanent improvements, we would be doing a greater measure of justice for not only the present generation, but for the generations to come.

I am familiar with Mr. Phillips' argument, but that is not engineering. Our business, as engineers, is to properly apportion the cost of each improvement to the community and to seek as intelligently as we can to apportion the benefits in a just and equitable way.

I have talked to people who sell bonds and they tell me that one of the troubles with the man who purchases, the investor, is that he wants a bond that does not mature within 40 or 50 years. He hunts other securities due to the fact the bonds mature and are paid off. Now, a 50-year bond, in the opinion of some people I have talked to, would be more attractive than the 30-year bond.

I would like to get Mr. Friel's reaction on the rates in Maryland. Are they higher or lower than we have in Pennsylvania?

And finally, the argument against the increase in the termination of the bonds, is that we are encouraging municipal extravagance. I don't think we are. We are just doing the opposite. If a community wants to pay it off in 30 years, they can do so, but they may, if they want, have 50 years. However, all the time those bonds are in existence, they are part of the bonded indebtedness of the community, which is limited to 7 per cent. I hope that the State of Pennsylvania will never get away from that 7 per cent limitation.

I am rather critical of all these sewer rentals, etc., which seem to me to be a way around to increase the 7 per cent limitation. In other words, we might find the best solution not in such matters as this sewer rental, as applicable to other communities as it may be, but simply by the increase in the termination of our bonded indebtedness.

Mr. Friel: I might say, Mr. Blum, we are governed by a law in Pennsylvania as to the life of the bonds, which is 30 years.

Mr. Blum: I know that.

Mr. Friel: In answer to your question about the rates in Maryland, naturally the annual rental would be lower. Over a long period of time your annual payment would be lower.

Mr. Blum: I didn't mean that; I meant the actual interest rate on the bonds.

Mr. Friel: I can't answer that. There are a couple of representatives here today from a Philadelphia bonding house, and their slant on the bonding situation might be of interest.

Going back to the discussion whether or not we should pay for the improvements for the future, I think, Mr. Blum, we had a different picture in 1907 and 1908 than we have today. They had no treatment as they do today, and today we have the problem of building sewage treatment plants, which means an increased cost of construction. And in addition, we are faced with the matter of carrying charges on these bond issues.

I lived up in Roxborough 40 years ago, and I don't think we had a bathroom then. I will venture to say that today all of the houses in Roxborough have bathrooms.

Today we are facing entirely different problems than we had to face 30 years ago.

Now, I will grant you that for a sewer lasting 50 or 60 years, the proper and scientific way to do is to so amortize the bonds. For a sewage plant that lasts 15 or 20 years, the bonding on that should be amortized in 15 or 20 years to get an exact relation, the same as setting up a rate structure on a water plant. Of course, here in this state we are limited to the 30-year period.

I think it would be of interest to get the slant of these bonding men who are here today.

President Grace: We would like to hear from any of the representatives of the bonding firms at this time.

Mr. Buckingham Miller (E. H. Rollins & Sons): I am not particularly well qualified to talk on the municipal interest rates, because my field is the engineering and promoting rather than the setting of interest rates. Frankly, I get them largely from our municipal specialists.

Regarding the actual interest on a long maturity issue, I would say it depends a good deal upon whether it is a low rate interest or high rate interest bond. Let us say that at around 4 per cent, I think long term maturities could be sold just about as well as a 25-year bond.

The maturity is rather important. It is always the longer term bonds that are harder to sell. Of course, in the short term bond you get a big premium, and on those bonds which are 20 years and upwards, you are apt to take a little loss. If you are selling bonds around 2½ or 2¾ per cent, there would be a very substantial saving in making them 40-year bonds instead of 25-year bonds. The average investor, if he is buying a 4 per cent bond nowadays, is pretty well satisfied to let it run a long while.

In the State of Pennsylvania, with the 8-mill tax, it makes our condition quite different than in other states. For instance, a 4 per cent bond in Maryland, owned by a Pennsylvanian is equivalent to a 3.2 per cent bond here. I mean on the exact return without reference to income taxes. Therefore, Pennsylvania bonds have to be figured out pretty much by themselves. Of course, as we all know, the good ones are at a very low interest rate.

TRENDS IN SEWAGE TREATMENT *

By Wm. A. Hardenbergh

Vice-President, Public Works Magazine, New York, N. Y.

Trends in sewage treatment may be considered from several angles. There is now a strong tendency toward a national program for reducing or eliminating stream pollution. During the past few years we have seen government financed agencies, such as the PWA and the WPA, give a tremendous impetus to the construction of sewers and sewage treatment plants; more construction of this kind is likely. And all of the time there is development and change going on in processes and in equipment, as well as increasing knowledge and technique in operation.

The PWA and the WPA.—Up to the end of 1938, PWA had allotted funds to 1525 sewerage projects, not all of which included treatment. The latest figures available for WPA are those of June 30, 1938, up to which time it had aided in the construction of 315 new sewage treatment plants and the improvement of 229 other plants. WPA is likely to be with us for some time, and since increasingly greater emphasis will be laid on "useful" projects, sewer systems and sewage treatment plants will probably continue to be built.

These two—the PWA and the WPA—have had a highly important part in sewerage construction through the tremendous volume of work initiated by them. On the other hand they have contributed disappointingly little toward any advance in the science of treatment. Among the reasons that may have contributed to this lack of progress are: Innovations were generally frowned on; the usual basis for the selection of equipment was the low bid; there was seldom time for more than routine investigation and planning—almost none for research to solve special problems. Consulting engineers, and state sanitary engineers, too, were jammed with work during the periods of PWA activities.

Stream Pollution Abatement.—There has been before Congress in various forms for the past two years or so a bill that is designed to create a national policy on stream pollution. Under the provision of this bill, the U. S. Public Health Service, working through the various state departments of health, will have the general responsibility for putting its policies into effect.

The need for a national policy in this matter is clear. Few municipal governments are willing to go ahead in removing pollution from streams so long as other communities in other states, or industries, continue to contribute enough waste to make the stream unfit for use. Likewise, a state can hardly be expected to place a burden on its industries by requiring them to treat all wastes, when the result will inevitably be that such industries will move to another less exacting state or will pass out of being because of competition from plants in states where there is no such burden. Thus, no state can afford alone to carry on a program of stream pollution elimination. A national policy that bears on all alike is needed.

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Such a program promises much from the viewpoint of development and progress, though the present bill seems deficient in providing any early effective action. It is likely that the Public Health Service will establish a research laboratory. In fact, such a laboratory has been in existence for some time, on a small scale, at the Cincinnati office. This should be expanded and placed on a field basis; that is, at least a portion of the work should be devoted to testing and developing methods already in fairly general use so as to determine their limitations and possibilities. Chicago has already done this in its experimental work. The sewerage field is fortunate in having attracted a number of excellent and well-trained young men; a research laboratory, to be worth while, must at least keep up with them.

Another probable development may be a more careful evaluation of the actual needs in treatment, with plants designed to produce an effluent that, under the conditions that exist in a particular locality, will not cause nuisance.

From the viewpoint of the operators, such a stream pollution abatement program should be of particular interest. Not only will new positions be created, but since many of these plants will handle industrial wastes, there will be openings in private industry as well as in public service; and with increased emphasis on costs, skilled operation will be needed. It is a good guess that these developments may lead still further toward licensing and grading of operators.

Financing Sewerage Construction.—During the past few years, Uncle Sam has been the principal financial agency in new construction, acting through the PWA and the WPA. This policy may continue for some time; and any program leading to stream pollution abatement will probably provide for long-time, low-rate loans to finance construction.

Sewer service charges or rentals have been increasingly used for financing sewage treatment plant construction. The usual bases for charges are: (1) water consumption, as shown by meters; (2) flat rates, generally based on size and type of buildings; (3) a charge based on the number and type of fittings. The first mentioned is the most common and probably the soundest. Modification may be necessary for those who have private water supplies which furnish all or part of the water used; and also for industries that produce wastes that are unusually difficult to treat.

The Outlook for Construction.—Continued activity in the construction of sewage treatment plants appears to be likely. The effect of the work relief agencies may be augmented soon to some small extent by stream pollution abatement work. In addition, enlargement and replacement of existing plants may be counted on as a considerable item.

Few plants go as much as 10 years without major improvements or changes.

TRENDS AND DEVELOPMENTS IN TREATMENT AND OPERATION

The trends in treatment continues to be toward the mechanical and chemical. Progress in this field in the past four or five years has been so rapid that it is difficult to realize the full extent of the advance. Screenings grinding or cutting; chemical coagulation; mechanical sludge dewatering; electrical, chemical, and mechanical controls—these are but a few of the fields in which there have been rapid developments.

It is being realized that a better knowledge of the nature of sewage —of these elements in it which affect treatment processes—is needed. Variations in strength, in composition and in components, whose importance are not well understood, are frequent, rapid, and extensive. Work by Hood at Ridgewood, N. J., has shown that the alkalinity may vary from 100 to more than 300 in three or four hours. At Buffalo, the chlorine demand of the raw sewage has varied from 30 to 560 per cent of the daily average. It is obvious that such wide changes render economical and effective treatment difficult.

There is almost no agreement as to what components or characteristics cause difficulties in treatment. For instance, work at the New Jersey Agricultural Experiment Station has shown that the demand for ferric coagulant is not correlated to the general strength of the sewage as measured by the B.O.D. and suspended solids; also that neither settleable solids nor particles larger than colloid size influence considerably the amount of chemical required for coagulation. It is known, however, that the amount of chemical required for coagulation varies greatly from hour to hour; that at times even an excessive amount of coagulant will not produce a satisfactory effluent; and that some sewages will not normally react with any coagulant to produce good results. These facts point to the need for further knowledge of the nature of sewage so that better treatment, more responsive to the will of the operator, will be possible throughout the entire day.

Measuring Sewage Flows.—The importance of measuring the amount and rate of sewage flows is now quite fully appreciated, and most new plants are being equipped with adequate measuring devices. With such treatment methods as activated sludge and chemical coagulation, accurate measurement of the rate of flow is necessary.

Screenings.—The time honored, but disagreeable and insanitary method of disposal of screenings by burial—honored more often in the breach than in the observance—is passing. Grinding or cutting of the screenings is now practically standard procedure, doing away with one of the most unsatisfactory jobs that the operator had to perform. This is a big step in bringing sewage plants out of the slums of public opinion. New York City has had good results in dewatering fine screenings with a centrifuge, and moisture reduction to 50 or 60 per cent is obtainable.

Garbage Grinding and Disposal into Sewers.—A few years ago, there was a good deal of interest in the grinding of garbage and its discharge into sewers. Little is now heard of this, due probably to the realization that such method of disposal would create costly new problems in sewage treatment without any corresponding advantages.

Sedimentation.—Sedimentation is the most important step in practically every method of treatment; except for small installations, the plain sedimentation tank with mechanical sludge removal apparatus is the standard. Both circular and rectangular tanks are used. New tank combinations have been introduced whereby two or more functions are performed in one tank, as flocculating and settling. New overflow weir arrangements to draw from quiet areas are being tried. The use of welded steel tanks has been studied, and steel tanks are now available. Except in unusual circumstances, it does not seem likely that they will replace concrete.

Chemical Coagulation.—Now that the first flush of enthusiasm has passed, the use of chemicals for coagulation is being given more careful and thorough study. One of the most interesting developments has been the higher standards of treatment that are now being demanded of this method. A chemical coagulation plant is not delivering the goods unless, with a 2-hour settling period, it is producing a clear or crystal clear effluent, with removal of all suspended solids, and a B.O.D. reduction of 75 per cent, exclusive of any secondary treatment.

In regard to chemicals, aluminum sulfate and Ferrisul have been demonstrated to produce excellent results, with satisfactory economy, especially in small plants. These chemicals can be fed with an ordinary dry-feed machine. With aluminum sulfate, no other chemical is ordinarily required, and with ferrisul not more than one other, which greatly simplifies application and control.

With any coagulant, digester supernatant must ordinarily be treated or be fed back slowly, and preferably at off-peak periods; morning high loads, especially on Monday, may cause poor coagulation; but developments now undergoing tests appear to control even these factors adequately and to permit the operator to maintain a clear effluent 24 hours every day.

The need for or advantage of pre-settling is still subject to some debate. Pre-settling does not seem to reduce the amount of coagulant required, but may permit better operation of the flocculator. Aluminum sulfate, for instance, appears to require a slow paddle speed, and in one plant where pre-settling was temporarily abandoned, trouble was caused by excessive sludge deposits in the flocculator, which finally resulted in clogging it. The paddle wheel type of flocculator seems to have some advantages over air-mix.

Chemical coagulation produces more sludge than plain sedimentation, and more sludge digestion capacity is required; overloading of digesters is likely when no more than 2 cu. ft. per person of sludge digestion capacity is provided. Indications are that 50 to 100 per cent more capacity is desirable. A higher gas production may be expected, up to or beyond 1.5 cu. ft. per person per day.

Conditioning and Controls.—Sulfuric acid has been used for conditioning sewage before coagulation. Its value appears to be doubtful. In some cases it reduces the quantity of coagulant required and improves the quality of the effluent; however, it has definite limitations, and when added in considerable quantity may interfere with the digestion of the precipitated sludge. It has been added both before and after the initial floc formation, and the latter procedure has shown some advantages.

Mechanical controls are being developed, which will make easier and more effective the routine of plant operation. One device regulates the application of chemical in accordance with the rate of flow of the sewage; savings from such a control more than justify its cost. Another recently developed control for sewage provides an automatic and continuous record of the pH and can actuate controls to maintain a desired pH or apply chemicals in accordance with pH values.

To be effective, in chemical treatment, controls must operate on the sewage entering or passing through the flocculator, since it is the condition of the floc in the first or second compartment of the flocculator that determines the quality of the plant effluent.

Amount of Coagulant.—Heavier applications of chemicals are now recognized as necessary, even for a normal sewage—that is one with a BOD of 250 or thereabouts. Probably an average of 700 pounds of chemical per million gallons will be required. During the peak four or five hours, the rate of application may be more than twice this average. These amounts of chemical are based on maintaining a clear or crystal clear effluent at all times. A very strong sewage may require slightly more, and a weak sewage a little less coagulant.

Some interesting microscopic studies have been begun on the crystal clear effluents—and the sludges—resulting from chemical precipitation. Preliminary data indicate there is often no life at all in the effluents, but that life is exceedingly active in chemical sludges except when more than 20 to 30 p.p.m. of sulfuric acid has been added as a conditioning agent, when a strong inhibitory effect is noticeable. The field for chemical precipitation may include its use for peak loads and for especially bad days, such as on Monday, or other heavy load periods.

Sludge Treatment.—The use of heated digesters continues to be standard; in few plants do digestion temperatures exceed 95°. There have been indications that, in many places, especially in northern areas, the commonly used design standard of 2 cu. ft. per person is inadequate, and there is now a tendency to allow up to 3 cu. ft. or even more. In the case of well-operated chemical coagulation plants, which remove more organic matter than plain sedimentation plants, the upper limit of capacity—3 to 4 cu. ft. per person—should be provided. Two-stage digestion seems to be advantageous in providing a greater flexibility to care for overloads and for the occasional periods when even the best of digesters misbehave.

The effect of sludge moisture content on sludge digestion and digestion tank capacity has been investigated by Sperry of Aurora, Ill.

Under the conditions existing there, Sperry found that a very thin sludge results in digester overloading; but if a thicker and less voluminous sludge is fed to the digesters, the capacity may be ample.

Vacuum filters are rapidly gaining in use for dewatering sludge and are now available even for very small plants. For the most part, these are used on digested sludge, but they will also satisfactorily dewater partly digested or raw sludge. They, therefore, can be used for a dual purpose—to supplement sludge drying capacities, and also to relieve temporary digester overloads. When used on partly digested or raw sludge, the resulting cake should be burned or buried promptly to avoid nuisance and fly production.

Centrifuges are still undergoing development; though some installations have been made, this method of sludge dewatering does not, as yet, seem to be fully accepted by engineers.

Vibrating screens will accomplish considerable dewatering of raw or digested sludge. Screens from 80 to 150 mesh are used. Not enough water can be removed to eliminate the need for further treatment or drying, but on either digested or raw sludge, moisture reduction to below about 85 per cent can be attained. Considerable research will be needed to determine the place of such screens in the field, if any.

Sludge drying beds are, however, still the most common means of dewatering sludge. In one plant where covered beds are used, and have proven inadequate in size, steam is to be used to hasten drying.

Sludge Utilization.—There are undoubted fertilizer values in sludge. The smaller plants do not produce enough material to justify any large expenditure for equipment to make processed sludge that will compete with commercial fertilizer. Nevertheless, there are so many uses for it, as for parks, lawns, etc., that there is full justification for preparing it in a form suitable for use by residents.

Secondary Treatment

There seems to be an increasing tendency toward fitting the degree of treatment to local needs in order to prevent nuisance and danger to health. Complete treatment costs money, both in construction and in operation, so that careful study is desirable to determine the necessity, either at the time of design or later, of complete treatment.

Trickling Filters.—In trickling filters the trend is overwhelmingly toward the use of the rotary distributor. Some states are now permitting higher rates on conventional trickling filters with this type of distributor. Previously, the standard rate of application for settled sewage has been 300,000 gallons per acre foot per day. New plants are being built for rates twice as great. In addition to better distribution, rotary distributors save head as compared to sprinkling nozzles.

There appears to be some evidence that effluents from chemical coagulation plants are more resistant to B.O.D. reduction by passage through a trickling filter than are effluents from plain settling tanks or Imhoff tanks, though Frith believes otherwise.

High Rate Filters.—Quite a number of recent plants have employed the so-called " high rate " filters. In these, the rate of application of sewage is generally between 10 million and 30 million gallons per acre per day. The maximum rate is usually based on the pounds of B.O.D. that the filter can handle, but there must be a sufficient volume of sewage flow to keep the organic matter scoured from the filter stones so that only a thin film remains. The rate of B.O.D. loading should not exceed about 1 pound per sq. ft. of filter surface per 24 hours, based on a depth of 8 ft. Stone particles should be 2 to 3-inch. Good circulation of air and uniform distribution of sewage to the surface are essential. Both preliminary and final settling are necessary.

B.O.D. reduction is usually not as good as with conventional type trickling filters and the effluent is not so clear because the high rate filter is unloading all of the time. Because of the high rate of application, filter flies do not breed, nor does ice form.

Magnetite or Laughlin Filters.—This type of filter is being used in a number of plants, principally for improving the quality of the settled or coagulated effluents. In addition to an improvement in appearance, the B.O.D. of the effluent is reduced from 30 to 50 per cent. Laboratory tests on coagulated effluents indicate that this type of filter may find a valuable field in connection with intermittent sand filters to produce a very high grade effluent.

Sand Filters.—These old timers may be coming back again. When preceded by effective chemical coagulation and a trickling or magnetite type filter, or perhaps without either, sand beds can handle 400,000 to 600,000 gallons per acre per day and produce a sparkling effluent with a B.O.D. of probably less than 10 to 20 p.p.m.

Better methods of application of the sewage to the beds are needed. Probably also more knowledge regarding most effective frequency of dosing and length of resting periods. Perhaps rotary distributors will prove effective for application, though they are rather costly.

Gas Utilization.—An interesting development is the rapidly increasing use of the gas produced from sludge digestion. This gas is normally used for heating tanks and buildings, operating gas engines and air compressors, and for other purposes. In some places it is being sold to power companies, or the power produced by it is sold. Nearly a dozen plants have tanks for equalizing the supply and demand. In a few, a schedule of pumping sludge has been worked out so as to produce the maximum amount of gas at the time it is needed. In one plant, the gas is to be used to make steam, which will be used to hasten sludge drying.

Plant Laboratories.—One of the most wholesome developments has been the increase in number of plant laboratories and in completeness of the equipment in them. In effect, this means that each plant has an embryo research laboratory capable of adding its contribution, large or small, to the total knowledge in the field. Many states, through short schools have furnished elementary instruction in those laboratory procedures that are of special value in regulating plant operation. The plant laboratories have been one of the big factors responsible for the interest in and growth of knowledge about sewage treatment.

Training of Operators.—Sewage works asociations, the short schools already mentioned, and the technical publications, have contributed to the increase in the knowledge of the rank and file of operators. During the past few years, simplified, handy versions of Standard Methods have been made available and much training material published.

Licensing of operators is already an accomplished fact in many states. The tendency will no doubt continue, and properly so. Most of those who have the will to do so, can learn all that is required to obtain a suitable license. The possession of a license is often some protection against political changes; and it is a first rate recommendation for a better job. With more and more new plants being built, more and better positions promise to be available.

I do not think that an operator needs to be an engineer or a chemist to be a top-notch operator. But he must have the backbone and the desire necessary to force himself to keep up to date and to learn those things that are necessary to make himself adequately fitted to do his work. To help him do that, and thus raise our present standards of sewage plant operation, is one of the important jobs of this Conference.

In this connection, it is a matter of much personal interest to me that the organization with which I am connected, published some 25 years ago, the first text on " Operation of Sewage Treatment Plants " written by one of your members, Col. Francis E. Daniels. It has also, I believe, published the latest text on this subject—September, 1938. The interest that has been shown by operators all over the country in this latest text has been most gratifying as illustrating their desires for additional knowledge.

A UNIQUE AND EFFECTIVE DETERMINATION OF THE EXTENT AND DEGREE OF POLLUTION BY SEWAGE OF THE WEST AND NORTH SHORES OF THE CITY AND COUNTY OF SAN FRANCISCO

By J. C. Geiger, M.D., C. G. Hyde, and A. B. Crowley

Department of Public Health, San Francisco

The General Problem of Shore Pollution.—The City and County of San Francisco occupies the northern end of the San Francisco peninsula and is surrounded by water on three sides: by San Francisco Bay on the east, Golden Gate Strait on the north, and the Pacific Ocean on the west. The length of the shore line is approximately twenty-three miles. There are thirty-one outfalls continuously discharging sewage at the shore line or into small estuaries and channels, the latter being located on the east side tributary to the Bay. Of this number, there are nineteen along the bay shore, eleven along the north shore, and but one on the west coast, near the extreme southwesterly corner of the city's incorporated area. In addition, there are at least ten storm overflows which occasionally contribute sewage diluted with rain water. The degree of dilution varies from low to high, according to the severity and duration of storms.

A magnificent stretch of wide sandy beach extending from the Cliff House southerly for about five miles constitutes the west coast line facing Pacific Ocean. From the Cliff House eastward to Aquatic Park, there are ten beaches of respectable size and several others which are small and not readily accessible. Along the bay shore in the southeasterly portion of the city there are two beaches worthy of consideration.

San Franciscians, as a group, are a nature loving, out-of-door people. On fine days they seek recreation at all available beaches, especially during the warmer portion of the year, from March or April through October. Some are hardy enough to indulge in swimming whenever and wherever the conditions are at all favorable.

Until within the past three or four years, no real effort was ever made to avoid the pollution of shores and shore waters or to improve the serious conditions which had been created. The discharge of sewage at many points along the shore, without adequate dilution or treatment of any sort, from the very beginning of sewerage in the various districts of the city, produced insanitary and obnoxious conditions. The situation is no longer tolerable and must be vastly improved if San Franciscans are to enjoy with safety and assurance the wealth of recreational values which Nature has lavishly bestowed. Fortunately, very effective steps are proposed to remedy these untoward conditions and at this writing significant progress has already been made.

Conditions Actuating the Study.—When the study to be described hereinafter was undertaken, it was, of course, known that the shores were grossly polluted. This was evident from the fecal and other sewage matters to be found on the beaches and in the coves. But it was not known to what extent sewage organisms were dispersed in the coastal waters and how the numbers varied with different conditions of tide and wind.

The investigation to determine the facts was undertaken and carried through by the Department of Public Health as its contribution to a comprehensive investigation looking to improved conditions.

Method Selected for Determining the Extent of Pollution.—After due consideration, it was decided to collect weekly samples extending over a considerable period of time from stations carefully selected to reflect the conditions along the west and north shores of the city. It was concluded that if a sufficient number of samples was collected at a sufficient number of places, all conditions of pollution as affected by tides and winds would eventually be represented.

The best criterion of sewage pollution has long been recognized to be the presence of members of the coli-aerogenes group of bacteria. Under the existing circumstances it was believed that the positive presumptive presence of this group of organisms would be sufficient. The relative numbers could be ascertained by thus determining the positive presumptive presence of the bacteria in question in varying amounts of the collected samples. This was done by using the following quantities: 10, 1, 0.1, 0.01, and 0.001 cc. If, for example, the organisms, *E. coli,* were demonstrated in one-thousandth of a cubic centimeter of a given sample, then it could be assumed with propriety that at least 1000 were present.

In practice two lactose broth tubes of each dilution were employed. These were incubated at body temperature, 37° C., and the presence of gas formers observed. If, at the end of twenty-four hours' incubation, gas occupying 10 per cent or more of the inverted vial in a fermentation tube was formed, it was considered to constitute a positive presumptive test. The work was performed in accordance with the Standard Methods of Water Analysis of the American Public Health Association and the American Water Works Association.

Selection of Sampling Stations.—Eighteen sampling stations were carefully chosen to reflect conditions of shore pollution between the Funston Life Guard Station on Pacific Ocean and Pier 45, just east of Fisherman's Wharf. The Funston Life Guard Station is near Fleishhacker Pool, 2400 ft. south of Sloat Boulevard and about 1.5 miles north of the southwest city limit. Pier 45 is about 4000 ft. westerly from Pier 37 where the main outfall sewer serving some 400,000 persons in the easterly portion of the city, constituting the North Point Sewerage District, discharges.

The distance between the sampling stations varied from 1800 to 6300 ft. and averaged somewhat less than 3600 ft. The total length of shore line covered was about 11.5 miles. In this stretch are located three main sewer outfalls of the city, namely, from east to west, Pierce

Street, Baker's Beach, and Mile Rock. In addition, the Laguna Street sewer at present contributes a considerable volume of sewage. There are also three important storm overflows; at Laguna Street, Baker Street, and Baker's Beach. Furthermore, there are one or two minor sewer outfalls maintained by the city, and several by the U. S. Government in the Presidio Military Reservation and Fort Mason. These are now (1939) in process of elimination through the construction of intercepting sewers to connect with the Marina Sewerage District system.

Program of Sampling.—The sampling was conducted weekly for one full year from February 6, 1933, to February 7, 1934. There were 52 sets of samples nearly all of which covered all stations. The samples were collected by an Inspector of the Industrial Division. The work of collecting a single series of samples ordinarily consumed two days because of the distances to be covered and the difficulty of reaching some of the stations. The collection of samples was 98.7 per cent complete. On rare occasions, a station was omitted for good cause.

Program of Laboratory Work.—As already indicated, all samples were tested in five dilutions, namely, 10, 1, 0.1, 0.01, and 0.001 cc. Two tubes of each dilution were inoculated, incubated, and examined for gas formation. In all, 9240 tubes were used. A perfect score would have been 9360 tubes, a difference of only 1.3 per cent.

Extent and Degree of Pollution as Revealed by Study.—Serious bacterial contamination was demonstrated at all stations, particularly along the entire north shore line east of Point Lobos. The greatest concentrations of sewage bacteria were found along the Marina, along Baker's Beach, and in the immediate vicinity of the Mile Rock outfall.

Throughout the section east of Point Lobos, the average numbers of *E. coli* were as follows:

In excess of 1 per c.c., 99 per cent of the time
In excess of 10 per c.c., 87 per cent of the time
In excess of 100 per c.c., 57 per cent of the time
In excess of 1000 per c.c., 40 per cent of the time

South of Point Lobos, along the ocean shore, the numbers averaged:

In excess of 1 per c.c., 76 per cent of the time
In excess of 10 per c.c., 30 per cent of the time
In excess of 100 per c.c., 9 per cent of the time
In excess of 1000 per c.c., 5 per cent of the time

Along Baker's Beach, where the degree of pollution was found to be highest, the average numbers were:

In excess of 10 per c.c., 100 per cent of the time
In excess of 100 per c.c., 87 per cent of the time
In excess of 1000 per c.c., 72 per cent of the time

At the easterly end of Crissy Field, west of the Yacht Harbor, the degree of pollution was very nearly equal to that at Baker's Beach.

RESULTS OF BACTERIOLOGICAL EXAMINATION OF SHORE WATERS OF SAN FRANCISCO, CALIFORNIA

Sta. No.	Dist. Feet btw. Stas.	Percentages of Samples and of Time when the Nos. of *B-Coli* per c.c. were as Great or Greater than the Values Indicated Below						Percentages of Samples Representing Stated Tidal Conditions			Estimated No. of *B-Coli* per c.c. Avg. for Period	
		0.1	1.0	10	100	1000	Avgs.*	Flood	Ebb	Slack	Min.†	Max.†
1	2400	95	73	26	6	0	40	44	54	2	8	50
2	4500	97	75	26	7	5	42	47	53	0	54	300
3	6300	94	71	27	6	4	40	47	53	0	45	240
4	4200	98	81	30	8	8	45	43	51	6	83	460
5	4500	98	79	43	16	6	48	43	55	2	73	400
6	1800	100	98	86	57	33	75	42	56	2	357	1960
7	5300	100	99	85	41	28	71	42	56	2	297	1640
8	1900	100	99	83	42	22	69	42	52	6	244	1340
9	1900	100	100	95	88	74	91	46	54	0	755	4150
10	1800	100	99	94	84	73	90	46	54	0	742	4080
11	4600	100	100	96	77	59	86	46	54	0	610	3350
11-A	4400	100	96	68	24	10	60	46	54	0	119	650
12	3500	100	100	91	63	37	78	44	54	2	399	2190
13	3500	100	100	99	88	69	91	40	54	6	710	3900
14	3500	100	100	83	48	34	73	42	56	2	358	1970
15	4100	100	100	95	56	32	77	40	52	8	348	1910
16	2400	100	100	76	26	13	63	44	56	0	148	820
17		100	99	83	53	34	74	44	54	2	362	1990
Average all Stas.		99	93	72	44	30	68	44	54	2	317	1740
Averages Stas. 1–5		96	76	30	9	5	43	—	—	—	57	310
Averages Stas. 6–17		100	99	87	57	40	77	—	—	—	420	2310

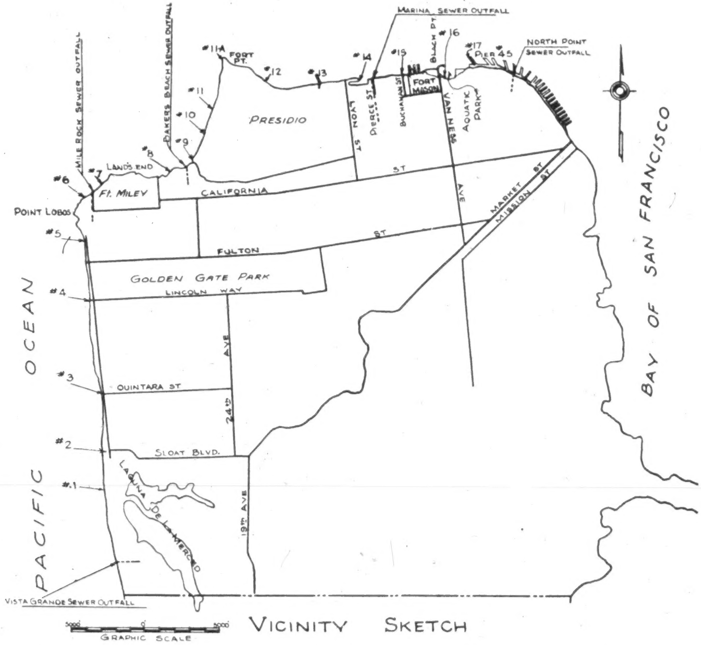
* Per cent positive tubes.

† Estimated as probable minimum and maximum numbers, respectively.

Distance: Vista Grande outfall to Station 1, 5000 feet; Station 17 to North Point sewer outfall, 3300 feet.

Even as far east as Buchanan Street, more than two miles east of the Golden Gate, the shore waters were found to contain upwards of 1000 *E. coli* for upwards of 30 per cent of the time.

The detailed results of this study are comprehensively presented in the accompanying table and chart. The locations of the stations are shown on the vicinity sketch which outlines the shores of San Francisco. For these the writers are indebted to the report of the Board of Consulting Engineers on the treatment and disposal of the sewage of the City and County of San Francisco, dated May, 1935, Plate 40.


MARINA SEWER OUTFALL
MILE ROCK SEWER OUTFALL
BAKERS BEACH SEWER OUTFALL
#11A
FORT PT.
#12
#13
#14
#15
BLACK PT.
#16
#17
PIER 45
NORTH POINT SEWER OUTFALL
#11
#10
#9
#8
#7
#6
LAND'S END
PRESIDIO
LYON ST
PIERCE ST
BUCHANAN ST
FORT MASON
VAN NESS AVE
AQUATIC PARK
FT. MILEY
POINT LOBOS
CALIFORNIA ST
MARKET ST
MISSION ST
SAN FRANCISCO
#5
FULTON ST
GOLDEN GATE PARK
LINCOLN WAY
#4
OCEAN
BAY OF
24th AVE
#3
QUINTARA ST
#2
SLOAT BLVD.
#1
PACIFIC
LAGUNA DE LA MERCED
19th AVE
VISTA GRANDE SEWER OUTFALL
5000 0 5000
GRAPHIC SCALE
VICINITY SKETCH

Sketch map of San Francisco showing boundary waters and locations of sampling stations.

Later studies have confirmed these results and have clearly demonstrated that sewage discharged by the North Point outfall at Pier 37 is carried westward in the shore waters on ebb tide and causes a high degree of contamination as far west as the Marina, a distance of approximately two miles.

Results of 52 sets of samples collected at approximately weekly intervals during the period Feb. 6, 1933, to Feb. 7, 1934, inclusive. All samples were collected and analysed by the Department of Public Health. Two tubes each of 10, 1, 0.1, 0.01 and 0.001 c.c. of all samples were incubated.

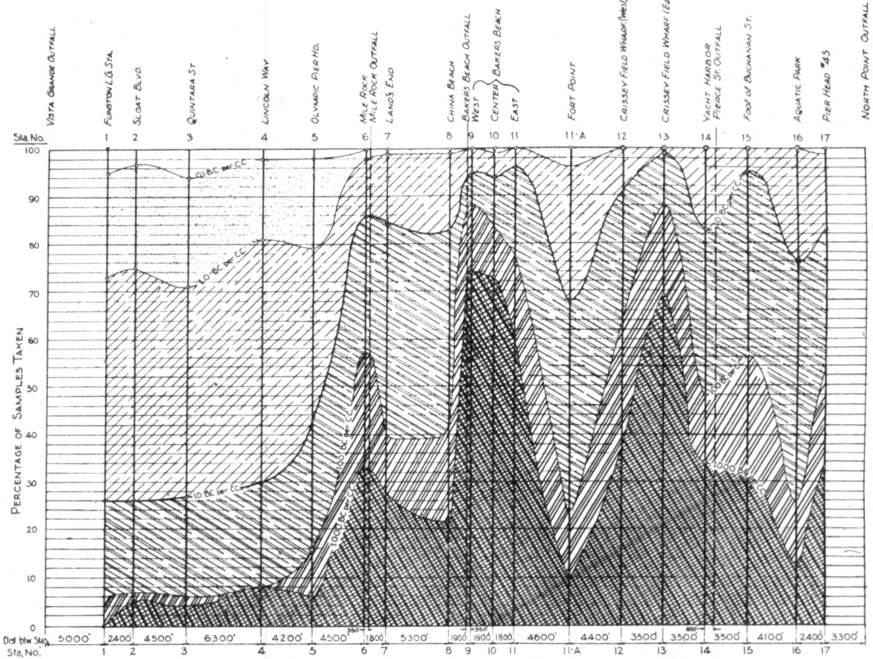


Chart showing numbers and locations of sampling stations and numbers of *E. coli* per c.c.

Note.—Samples were taken at the shore at all stations except Nos. 12, 13, 14 and 17. In each zone the numbers are greater than indicated by the top line and less than indicated by the bottom line.

Use of Data.—This innovation in field and laboratory investigations of such a large body of water, affecting many bathing places, brought forth data that could be put to excellent use by the Department of Public Health.

Some of the beaches were used for bathing quite regularly by the citizenry, contrary to the advice of the Department of Public Health. Certain civic groups assumed that the waters were not fit for bathing, and on various occasions demanded quarantine orders against bathing in these areas.

From this comprehensive study the Department of Public Health had positive evidence of the degree of pollution existing in the waters along the westerly and northerly shores where the most frequented and popular bathing beaches are located.

After due publicity of the findings, definite quarantine was placed against bathing in these waters. Prohibition of bathing resulted in many pointed inquiries from civic organizations and citizens, which could only be satisfactorily and convincingly answered by reference to the data available as the result of field and bacteriological studies of the waters in question. The inauguration of this unusual survey followed a long period of careful planning and strategy within the Department of Public Health. The department was aware of the undesirable existing conditions, but did not possess sufficient scientific evidence to procure the desired support of the general public.

Prohibition of bathing in these areas brought about the hoped for psychological effect amongst the citizenry. Demands were made of city officials for correction of the potential health hazard and aesthetic nuisance.

As a result a special bond election was called and bonds in the sum of $2,625,000 were voted to cover the cost of construction, under the U. S. Public Works Administration, of improved sewerage and sewage treatment works. Approximately $1,580,000 have been expended upon works directly concerned with the improvement of conditions along the north and west shores. The sewage of the Marina District is being pumped easterly to Pier 37 where it will eventually be treated in combination with that of the North Point Sewerage District. The Marina District includes the U. S. War Department Posts in the Presidio Military Reservation and at Fort Mason. The sewage of the Baker's Beach, Richmond and Sunset Districts is being effectively treated, prior to disposal through the Mile Rock outfall, at a plant located in Golden Gate Park. A small area in the Baker's Beach District remains to be connected with the sewers contributing to that treatment plant.

SUMMARY

The City and County of San Francisco is bounded on the west, north, and east by the Pacific Ocean, Golden Gate Strait, and the Bay of San Francisco. Of the twenty-three miles of shore line, five miles constitute a magnificent beach on the shore of the Pacific Ocean. In addition, there are twelve other beaches suitable for bathing if and when pollution by sewage is abated. The steps already taken to improve conditions have been outlined above.

Bacteriological examination of the water was made by collecting weekly samples from eighteen carefully selected sampling stations. The presence of members of the coli-aerogenes group was the criterion used to estimate the degree of sewage pollution in the samples. Dilution in quantities of 10, 1, 0.1, 0.01, and 0.001 in two tubes each was employed, and the work was performed in accordance with Standard Methods of Water Analysis. Samples were taken for a continuous period of fifty-two weeks and a total of 9240 tubes were used. Serious contamination was demonstrated at all stations. The data available as the result of the study constituted the basis for quarantine order against bathing at the beaches in question. They were used extensively in convincing the public that funds should be made available for correction of the undesirable conditions.

Conclusion

Undoubtedly the unique method employed by the Department of Public Health instilled in the minds of San Franciscans the need for attacking the problem of pollution of bathing beaches from sewage. For many years prior to this investigation, people seemed to regard this condition as an accepted thing and could not be stirred from their lethargy to face the problem.

The unusually heavy favorable vote for sewer bonds (which prior to this election were usually defeated) indicated that tactful planning by Health Departments in attacking certain problems to which the public seem indisposed can produce favorable psychological effects resulting in full support and cooperation.

The San Francisco Department of Public Health is satisfied that the year's work expended in this innovation was well worth while.

CONTINUOUS DIGESTION OF MIXTURES OF SLUDGES FROM DOMESTIC SEWAGE AND PACKINGHOUSE WASTES

By O. J. Knechtges, Francis M. Dawson and M. Starr Nichols *

Packinghouse waste is treated economically in some cities along with domestic sewage. In some places the packinghouse waste solids are settled in tanks independent of the domestic sewage. Digestion of the solids may be undertaken separately or as a mixture.

Batch digestion experiments on mixtures of domestic and packinghouse sludges carried out by Knechtges, Dawson and Nichols,[1] indicated that such mixing of the sludges would not hinder the digestion in any way and might even prove a beneficial procedure in those cases where both sludges are produced. Since the results were obtained from batch digestion rather than the usual continuous method, it was thought highly desirable to conduct a study of continuous digestion of these mixtures to which daily additions and withdrawals were made. In a continuous digestion experiment in which fresh sludge is added daily to a digester, the composition of the singular additions will average over a period of time. The authors estimated that a period of 100 days of continuous digestion would furnish sufficient data from which reliable conclusions may be drawn so as to answer the question whether it is feasible to mix the two sludges from the viewpoint of digestion.

Experimental

The apparatus used in the batch digestion work and described elsewhere [1] was used in the present experiments. The sludge digestion units were incubated at 30° C. in a constant temperature air chamber with a maximum error of ± 2° C. This continuous experiment was conducted by adding and removing daily the same volume of sludge from the 10-liter units. No supernatant liquor was removed. The entire contents of a digester were thoroughly mixed by shaking before sludge was removed. As described later, the concentration of solids in the fresh sludge added to a digester was maintained as nearly constant as possible.

For this experiment it was estimated that sufficient data would be available to predict the best operating conditions if a range in the percentage daily additions from a minimum of 2 per cent to a maximum of 8 per cent by volume were undertaken. This corresponds to adding and removing a volume equal to the capacity of the digester in 50-day and 12½-day periods, respectively.

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* From the Department of Hydraulic and Sanitary Engineering and Wisconsin State Laboratory of Hygiene, Univ. of Wisconsin, Madison, Wisconsin.

TABLE 1
ANALYTICAL RESULTS

	SERIES 1					SERIES 2					SERIES 3					SERIES 4					SERIES 5				
	PURE DOMESTIC					2 DOMESTIC 1 PACKING					1 DOMESTIC 1 PACKING					1 DOMESTIC 2 PACKING					PURE PACKING				
1											BOTTLE NUMBER														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2							PER CENT				DAILY ADDITIONS					BY VOLUME									
	3.50% SOLIDS					4.00% SOLIDS					4.25% SOLIDS					4.50% SOLIDS					5.00% SOLIDS				
	2	4	5	6	8	2	4	5	6	8	2	4	5	6	8	2	4	5	6	8	2	4	5	6	8
3							TOTAL SOLIDS				ADDED PER DAY PER					CU FT OF DIGESTER									
	.0438	.0876	.1096	.1320	.175	.050	.100	.125	.150	.200	.0531	.1062	.133	160	.2125	.0562	.1127	.141	.169	.225	.0625	.125	.1564	.188	250
4											AVERAGE pH VALUES														
	7.1	7.0	7.0	6.9	6.9	7.2	7.0	7.0	6.9	6.9	7.2	7.2	7.0	6.9	6.8	7.1	7.0	6.9	6.9	6.9	7.1	7.0	6.9	7.0	6.8
5							TOTAL SOLIDS -				PERCENTAGE					- AS REMOVED									
	2.42	2.49	2.42	2.37	2.57	2.57	2.77	2.98	3.00	3.38	2.82	2.80	3.10	3.26	3.82	2.88	3.03	3.39	3.34	3.97	3.10	3.75	4.20	4.26	4.55
6							PER CENT -				VOLATILE SOLIDS					- AS REMOVED									
	55.8	56.9	58.3	60.5	61.6	56.2	58.5	59.5	61.7	63.0	53.9	58.7	62.8	64.3	67.8	55.3	59.5	62.2	67.5	67.6	55.0	58.8	64.6	67.3	70.0
7						GAS - C.C PER DAY -					PER GRAM OF SLUDGE					- ADDED DAILY									
	59.5	54.0	53.7	52.8	45.5	62.8	60.0	58.2	53.7	43.0	71.4	58.1	51.7	48.2	36.5	66.1	56.1	56.3	46.6	37.9	74.6	52.2	34.9	30.7	23.5
8						$CHCL_3$ EXTRACT					% OF TOTAL SOLIDS					- AS REMOVED AT 100 DAYS									
	13.5	12.5	14.0	12.4	17.5	10.4	10.1	11.2	8.5	14.2	8.5	10.3	10.1	15.5	16.9	11.5	12.3	11.5	11.8	16.5	8.3	10.8	28.8	31.9	31.0

This study comprised 25 digestion units of 10 liters of sludge each, contained in 20-liter bottles. These consisted of five different mixtures of domestic sewage and packinghouse sludges with five different percentage daily additions of fresh sludge mixtures (see Table I). The bottles 1 to 5 contained pure domestic sewage sludge; bottles 6 to 10 contained two parts of domestic to one part packing by volume; bottles 11 to 15 contained one part of domestic to one part packing; bottles 16 to 20 contained one part of domestic to two parts packing; bottles 21 to 25 contained pure packinghouse sludge.

For each group of five bottles, removals of digesting sludge and additions of fresh sludge mixtures of 2 per cent, 4 per cent, 5 per cent, 6 per cent, and 8 per cent by volume were made daily. The proper volume of sludge was removed daily through a bottom spout, and then the same volume of fresh sludge was forced into each bottle through the same opening with a plunger pump. These volume additions were accurate to about 5 per cent.

Completely digested sludge mixtures corresponding to the proportions in the five groups were available from previous batch experiments. In order to prepare active biological life, the digestion units were filled to 90 per cent of their capacity with "dead ripe sludge" and 10 per cent by volume of fresh sludge added to complete the mixture. After 15 days' incubation of this seeding mixture gasification had slowed down. This resulting material constituted the starting sludge for these continuous digestion experiments.

Through the courtesy of the Madison Metropolitan Sewerage District fresh sludges were received daily at the Hydraulic and Sanitary Laboratory of the University of Wisconsin where the experiments were conducted.

During the first 20 days the fresh sludges and sludge mixtures were added with the same solids concentration as delivered. During the remainder of the 100-day test the solids concentration of the delivered sludges were determined gravimetrically and then diluted to 3.5 per cent solids for the domestic and to 5.0 per cent for the packinghouse sludge. The average percentage volatile solids was 75 for fresh domestic and 77 for fresh packinghouse sludge.

Since during the first 25 days the digesting sludges probably approached a rather constant fermentation rate similar to that which would be obtained after a long period of digestion, the analytical results in lines 4 to 8 of Table I are the average of all the results determined during the ensuing 75 days of the experiment when digestion rates had probably reached an equilibrium.

pH Results.—At the time of starting the experiment it was believed that in the bottles of high solids additions, low pH levels would develop. However the results of line 4 of Table I show that the pH remained between 7.2 for the units with 2 per cent daily additions and 6.8 for the 8 per cent additions, with intermediate values for the other percentage additions. No lime was added to these mixtures at any time. Digestion of sludge on a 12½-day schedule (8 per cent additions) showed

TABLE 2

	Series 1					Series 2					Series 3					Series 4					Series 5				
	Pure Domestic					2 Domestic 1 Packing					1 Domestic 1 Packing					1 Domestic 2 Packing					Pure Packing				
	Per Cent Daily Additions by Volume																								
1	2	4	5	6	8	2	4	5	6	8	2	4	5	6	8	2	4	5	6	8	2	4	5	6	8
	PART 1 - STUDY based on Total Solids passing thru 10 Liter units in 100 Days																								
	Liters of Sludge - Added and Removed																								
2	20	40	50	60	80	20	40	50	60	80	20	40	50	60	80	20	40	50	60	80	20	40	50	60	80
	Grams of Total Solids-Added																								
3	700	1400	1750	2100	2800	800	1600	2000	2400	3200	850	1700	2125	2550	3400	900	1800	2250	2700	3600	1000	2000	2500	3000	4000
	Grams of Total Solids-Removed																								
4	485	997	1209	1420	2057	515	1108	1489	1801	2704	564	1120	1548	1954	3057	576	1212	1694	2003	3178	621	1500	2100	2554	3643
	Grams of Total Solids-Decomposed to Gas																								
5	215	403	541	680	743	285	492	511	599	496	286	580	577	596	343	324	588	556	697	422	379	500	400	446	357
	Relative Digestion of a Unit computed on the basis that the 2% unit of each series is 100% digested																								
6	100.0	93.8	101.	106.	86.4	100.0	86.4	71.8	70.0	43.5	100.0	101.0	80.6	69.5	30.0	100.0	90.6	68.7	71.7	32.6	100.0	66.0	42.2	39.2	23.6
	Total Solids Decomposed per Day per Cu Ft of Digester																								
7	.0134	.0252	.0338	.0424	.0464	.0178	.0307	.0320	.0374	.0308	.0179	.0362	.0360	.0372	.0214	.0202	.0367	.0348	.0435	.0264	.0237	.0312	.0250	.0278	.0223
	PART 2 - STUDY based on the Gas produced from Units containing 10 Liters of Sludge																								
	C.C. of Gas per Day																								
8	417	756	940	1110	1272	503	960	1164	1290	1375	607	990	1100	1230	1240	595	1010	1265	1260	1364	746	1044	873	921	940
	Relative Digestion of a unit computed on the basis that a 2% unit of each Series is 100																								
9	100.0	90.7	90.2	88.7	76.4	100.0	95.5	92.7	85.5	68.5	100.0	81.4	72.4	67.5	51.1	100.0	84.9	85.2	70.5	57.4	100.0	70.0	46.8	41.1	31.5
	Per-cent daily volume additions which may be 100% digested - as computed from the relative gassification values shown in line																								
	3½% Solids					4% Solids					4¼% Solids					4½% Solids					5% Solids				
10	2.0	3.63	4.61	5.32	6.11	2.00	3.87	4.64	5.13	5.30	2.00	3.26	3.62	4.05	4.09	2.00	3.40	4.26	4.23	4.59	2.00	2.80	2.34	2.47	2.52
	Per Cent Daily Volume Additions of 5% Solids which may be 100% digested - as computed from line 10																								
11	1.40	2.54	3.23	3.72	4.28	1.60	3.10	3.71	4.11	4.24	1.70	2.78	3.08	3.45	3.48	1.80	3.06	3.84	3.81	4.14	2.00	2.80	2.34	2.47	2.52

continuous satisfactory action without the production of an acid reaction of a magnitude sufficient to slacken fermentation. On one occasion a daily collection of fresh packinghouse sludge had a pH below 5.0 when received, but the addition of this sludge to bottle No. 25 caused no noticeable drop in pH for the digesting mixture.

Chloroform Extract.—Little research has been carried out on the fermentation of lipids compared to that done on carbohydrates and proteins. The concentration of fat-like substances in sewage sludges varies from approximately 20 to 40 per cent while that in grains, which form the base in most commercial and agricultural fermentations, is from about 2 to 4 per cent. Lipids constitute the major constituent that is decomposed in the digestion of domestic and packinghouse sludges. The fresh domestic sludge added during the last 36 days contained an average of 38.8 per cent, and the fresh packinghouse sludge 41.2 per cent lipids on a dry basis. The sludges were allowed to digest 50 additional days after the 100th day addition. This time proved sufficiently long so that the lipid content of the 8 per cent addition had been reduced to the lipid content of the 2 per cent addition. Residual lipid-like substances, 12.2 per cent for the ripe domestic and 8.5 per cent for the packinghouse, remained in the solids after practically all gasification had ceased.

The results of digesting sludges at 100 days (Table I, line 8) showed that the major portion of the lipids which usually disappear in complete digestion has been decomposed in most bottles. However, the residual values for the 5, 6 and 8 per cent daily additions, ranging from 28.8 to 31.9 per cent, indicate that the lipids had not been materially reduced in these packinghouse sludges and that digestion was far from complete.

Total Solids, Volatile Solids, and Gas Results.—The total and volatile solids contents of the digestion mixtures were determined weekly. The average results are recorded in lines 5 and 6 of Table I. These results show that it is probable that the sludge of the 2 per cent daily additions was totally digested and that a volatile solids percentage of 55 can be taken as an indication of complete digestion. Inspection of the solids, gas, and lipid results as shown in lines 5, 6, 7 and 8 of Table I indicate a definite trend in decomposition since a high percentage (6 to 8 per cent) of fresh domestic solids of 3.5 per cent solids can be added daily and satisfactorily digested, whereas a lower percentage (2 to 4 per cent) of fresh packinghouse sludge is seen to be the capacity limit.

The data of Table I have been used to calculate the data of Table II. A total solids balance was attempted, even though the solids concentrations of the material removed from a bottle were determined but once a week. This solids balance as shown in Part I of Table II was calculated as follows, for example referring to bottle 5: Eighty liters of sludge added, containing 3.5 per cent solids, shows that 2800 grams of fresh solids were added at times additions were made. Eighty liters of digesting sludge, containing 2.57 per cent solids at the times removals were made gave 2057 grams of digesting solids removed from this bottle in 100 days. The difference of 743 grams represents the amount of solids which disappeared (converted to gas, etc.). A similar computation was made for each of the 25 bottles. The relative amounts of digestion in the various units of each series has been computed from the data of line 5 and recorded in line 6. These values are computed on the basis that the 2 per cent unit of each series is 100 per cent digested. The average daily gas production from each bottle is shown in line 8. The relative amounts of digestion of the various units of each series have been recorded in line 9 as *computed from the gas results* of line 8 and on the basis that the unit of 2 per cent daily addition is completely digested. The calculated values of lines 6 and 9 are not in full agreement. The authors believe that the values calculated from the gas results are probably more reliable, since the gas rates were obtained at least twice a day for every day whereas the total solids were determined but once weekly, and also because sampling errors do not enter into the gas results. The figures of line 9 were used to calculate the values of lines 10 and 11. The results of line 10 are computed as follows, for example: Bottle 5 is considered 76.4 per cent digested relative to bottle 1 and hence 0.764 × 8.0 = 6.11 per cent daily volume additions of 3½ per cent fresh solids may be considered completely digested. In line 11 the values of line 10 are computed to a similar basis of 5 per cent solids concentration. The results of line 11 show that the packinghouse sludge, which has not been mixed with domestic sludge, has not digested so rapidly as has unmixed domestic, nor as rapidly as mixtures of the sludges. The results of line 11 also show that mixtures of Series 4 (1 domestic to 2 packing by volume) or (1 domestic to 2.86 packing by weight) digest as rapidly as does unmixed domestic sludge, Series I.

From the maximum values of line 11 of Table II, Table III has been computed. Sample computations for domestic sludge are as follows: 4.28 per cent by volume of 5.0 per cent solids added per day is equivalent to 4.02 lb. of dry solids added per month per cubic foot of digester. Therefore a digester of a capacity of 7500 cu. ft. would be required to digest 1000 lb. of domestic solids per day (see Table—1000 ÷ 0.134 = 7500). This table indicates (last line) that less volume would be required to digest 1000 lb. of domestic and 2860 lb. of packinghouse solids per day when mixed than when the same amount of solids are treated in separate compartments (30,000 cu. ft. compared to 40,000).

TABLE III

Subject	Domestic	Packing	1 Domestic 2 Packing
Percentage daily volume additions of 5% solids which may be 100% digested (max. values of line 11)	4.28	2.80	4.14
Solids added per month per cu. ft. of digester	4.02	2.62	3.86
Solids added per day per cu. ft. of digester	0.134	0.0874	0.128
Solids per day to be digested, cu. ft.	1000	2860	3860
Digester capacity required, cu. ft.	7500	32500	30000
Digester capacity required, cu. ft.	40000		30000

In Table IIA of a previous paper [1] on batch digestion are recorded the average values for a 100-day period for the grams of solids converted to gas in 10 liters of space: for Series 1, pure domestic—97; for Series 2—157; for Series 3—152; and for Series 5, pure packing—195. These results may be reviewed with those of line 5 of Table II. The comparison shows that domestic sludge solids were converted to gas at a rate 743 ÷ 97 = 7.65 times as rapidly in continuous digestion as compared to batch digestion; also that packinghouse solids were converted to gas 500 ÷ 195 = 2.65 times faster with continuous digestion. This increased rate of digestion seems logical inasmuch as in continuous digestion the same biological life is active from day to day and for that reason there is no lag in fermentation, whereas in a batch digestion, biological life changes with the stages of digestion and consequently digestion varies and averages slower. However, the peak gas rates are of greater magnitude in batch digestion than the day-to-day rates in continuous digestion. Table IV has been prepared to show this comparison:

TABLE IV

Ratio of Domestic to Packing	Cc. of Gas per Day per Liter of Digestion Capacity			Ratio of 4 ÷ 3
	Continuous Digestion		Batch Digestion Gas Rate at Peak	
	Bottle No.	Gas Rate		
1	2	3	4	5
Domestic	5	127.4	319	2.50
1-2	10	137.6	569	4.14
1-1	15	124.1	403	3.25
2-1	20	136.4	470	3.45
Packing	22	104.4	554	5.30

The values of column 4 have been computed from data published in a previous paper.[1]

Table V is a tabulation of published results of full-scale digestion tanks. The solids added to digesters vary over a wide range from .0294 for Lima, Ohio to .305 for Cedar Rapids, Ia. (pounds per day per cu. ft. capacity) while the solids additions in this experiment ranged from .0438 to .250, as shown in Table I, line 3. For full-scale digesters solids decomposed varied from .010 to .181, while in this experiment solids decomposed varied from .0134 to .0464 lb. per day per cu. ft. as shown in line 7 of Table II.

CONCLUSIONS

The results show that there is a distinct advantage obtained in the rate of digestion when primary settled fresh packinghouse sludge and domestic sewage sludges are mixed.

TABLE V

Reference	Place	Type	Notes	Temp.	Solids in Raw Sludge	Solids in Sludge Drawn	Total Solids to Dig.	Volatile Solids to Dig.	Pounds of Solids Decomposed
				°F.	%	%	Lbs. per	Day per	Cu. Ft.
1	Salem, Ohio	Act.		78–82	5.3		.0326	.0211	.0165
2	Peoria, Illinois	Act.	Sin. Stage	90	5.3	3.8	.060	.040	.0204
		Act.	1st Part of 2 Stage	91	3.02	2.47	.1185	.0857	.0372
3	Lima, Ohio	Act.		88			.0294	.0181	
4	Galesburg, Ill.	Filt.		82	7.3	13.9	.0295	.0176	.010
5	Coney Island, N. Y.	Prim. Chem.	Max. Month	80–83	8.6		.067	.0451	
		Prim. Chem.	Ave.	80–83	8.6		.040	.0264	
6	Cedar Rapids, Ia.	Filt.	Max. Month				.479	.280	
		Filt.	Ave.				.305	.235	.181
7	Cleveland, Ohio						.187	.150	
8	Grand Rapids, Mich.	Prim.			4.9	12.9	.0586	.0397	.0219

Peoria solids contains waste of Commercial Solvents; Cedar Rapids-packinghouse.

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Primary settled sludge of Madison domestic sewage digested more rapidly in continuous digestion than in batch digestion.

Comparison of results of batch and continuous digestion shows that the prediction of rates of sludge fermentation is most reliable when based on experiments in continuous digestion. The results show that predictions made from a batch digestion experiment may vary widely from the average large-scale fermentation rate. This is probably because decomposition in batch digestion depends on but one sample of sludge and on one condition of fermentation.

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Reference

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CHEMICAL PRECIPITATION OF TEXTILE WASTES AND STUDIES OF pH CONTROL *

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Large volumes of liquid industrial wastes are produced in the processing and dyeing of textile fibers. The quantity and strength of these wastes have created conditions of stream pollution that must be abated. The scope of this problem may be estimated from a survey conducted by the State Board of Health of North Carolina in 1930,[1] in which it was reported that of 430 mills in North Carolina, 147 were discharging a total of 59,000,000 gallons of waste per day, of which 7,200,000 gallons were sufficiently concentrated to receive treatment. Of the latter, 4,000,000 gallons consisted of kier liquor, 865,000 direct color wastes, 935,000 sulfur colors, and 1,400,000 miscellaneous strong wastes including indigo, vat, color-shop, etc. If the strength of the wastes is taken into consideration and compared on a basis of domestic sewage equivalents, the pollutional effect of these discharges is greatly increased over an equivalent volume of sewage.

The difficulty of treating textile wastes is indicated in a general survey of reports on this subject. Although sulfur colors and kier liquors are the most difficult to treat, other colored wastes are also important because their presence is betrayed by their color, thus causing the riparian owner to complain, although pollutional conditions may not exist.

The obvious importance of this problem of industrial wastes has led, through previous studies on its treatment,[22, 23, 24] to the studies on chemical precipitation reported herein.

Most studies on chemical precipitation have used a trial and error method. This procedure appears to persist in the operation of chemical precipitation plants. The authors believe that a more rational approach to the subject is necessary. The importance of hydrogen-ion control is recognized but there appears to be a lack of correlative data. Streander [4] states that various sewages have variable isoelectric points of optimum pH conditions for proper dosages. Thomas [5] accounted for this variation by the fact that there is an isoelectric range. In the case of a substance insoluble over a wide range, values for the isoelectric point have been reported at various points over that range. Minimum solubility and optimum agglutination occur at the isoelectric point under simple conditions. Clark [6] notes that Michaelis [7] could account for the displacement of the precipitation optimum from the isoelectric point by the influence of salts, and cautions against considering the isoelectric point as always identical with the point of maximum precipitation. The determination of the pH will not distinguish whether its observed influence is direct or indirect, but, even though it may act indirectly through remote channels, the hydrogen-ion concentration may be important. Therefore, advantage should be taken of the comparative ease with which the concentration of hydrogen ions can be determined; thus its influence may be followed or it may be controlled as a constant during the study of any other factor which may influence a process. If observations show that the various coagulants precipitate within a definite pH range, and that variations from this range are dependent upon other conditions, such as the presence of other chemicals, an enormous field in waste precipitation may open. The experience obtained in the coagulation of waters may then be applied to waste treatment.

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The methods by which chemicals act to bring about purification may be summarized as follows [8]:

1. Formation of insoluble or very slightly soluble precipitates which enmesh suspended solids and mechanically carry them down.
2. Adsorption of dissolved or colloidal solids on the large surfaces presented by the precipitate.
3. Ionization to yield high-valent ions that may neutralize the electrical charges on colloidal particles and cause them to aggregate and settle.
4. Ionization of the precipitant to yield hydrogen or hydroxyl ions, thus rendering the waste more acid or more alkaline.

It is essential to bear in mind these methods of purification. The variations in the optimum pH zone and the displacement of the minimum solubility point from the isoelectric point may be explained by one of these phenomena. In the case of textile wastes, the chemicals used in the preparation of the dye solution are also very important.

Object.—The objects of this work may be outlined as follows:

1. To ascertain those chemicals best adapted for the precipitation of textile wastes and the best method for their application.
2. To determine the pH range of coagulation by selected reagents.
3. To note any correlation between the hydrogen-ion concentration and the degree of precipitation for the various coagulants used.

Description of Wastes

The textile wastes chosen for this study were those that have been the main offenders because of their volumes, strengths, or tinctorial properties. Textile wastes [3] and dyestuffs used for textiles [2] have been described in general. However, a description of the materials used in these studies follows:

Sulfur colors are included in the general group of substantive dyes. They consist of sulfur compounds and are usually applied with the addition of sodium sulfide. The waste from these dyes is of importance as it contains the pigment (a sulfur compound), sodium sulfide, salt, and some minor chemicals. The presence in large quantities of sodium sulfide, a reducing agent, will upset biological processes by exerting a high demand for oxygen. The prevention of odors resulting from the production of hydrogen sulfide is also a vital point in the disposal of this waste.

Direct colors do not require the use of accessory chemicals to increase the absorption of the dye by the goods or to increase the solubility of the dyestuff, but act directly on the cloth. Common salt (sodium chloride) or Glauber's salt (sodium sulfate) is employed to reduce the solubility of the dyestuff and consequently to force the color into the cloth. The waste from this type of dye will contain coloring matter, salt, a little water-soluble oil, and impurities from the cotton. The difficulty of removing color from such waste is well known.

Developed colors employ original dyestuff as a direct color in dyeing. After the application of the dyestuff, the absorbed color is converted to an unstable diazo body by treatment with nitrous acid formed by sodium nitrite and sulfuric acid. The unstable azo body is converted to a stable azo dyestuff by means of a developer which is usually beta-naphthol. Three main wastes are obtained from this process: spent dye liquor, diazotizing bath, and developer.

Naphthol colors are applied in practically the reverse process as that for the production of developed colors and similar wastes are produced.

Vat dyes are applied in a special kind of a dyebath in which the dye is reduced to a soluble form by means of a strong reducing agent, such as hydrosulfite. These dyes are highly insoluble in water but yield reduction products soluble in an alkaline solution. The dyebath, therefore, consists of a mixture of the dyestuff, a strong reducing agent and an alkali; such a mixture is termed a vat.

Indigo is a vat color but is discussed separately as some mills use only this dye and have constructed special machines for its application. Indigo is used mainly in the dyeing of chain warps. The yarn first enters a compartment containing a hot solution of caustic soda which removes the greases and wax from the fiber, thus making the cotton more absorbent. The caustic is removed by washing in a second compartment, and the yarn then passes into the vats containing the reduced indigo. Following the indigo bath, the yarn is carried over many reels in order to expose it to the air and bring about the oxidation of the reduced compound. The colored yarn is then washed and finally passed through a softening bath containing a mixture of oil and waxes. The waste from the indigo machines is produced continuously by overflow from the wash boxes; the caustic bath and dye vats being seldom discharged. The resulting waste contains caustic, sodium hydrosulfite, reduced indigo, and some oil and waxes. The liquid has a green appearance but turns blue upon contact with the air.

Aniline black is produced by the oxidation of aniline in an acid solution by such agents as chlorates, chromates, or ferrocyanides. This dye is expensive and seldom dumped; therefore, the waste produced in this process is mainly soapy wash water containing some mineral matter and aniline dye washed from the cloth.

Kier liquor is obtained from the process of kiering cotton in the preparation of the cloth for dyeing or bleaching operations that may follow. This process removes the natural fats, waxes, greases, and other substances such as fragments of the boll from the cloth. Treatment consists of boiling the material for several hours in a highly alkaline solution containing about two per cent caustic soda and one per cent soda ash per weight of goods. The waste kier liquor has a total alkalinity of approximately 1 to 2 per cent, and contains the chemicals of the caustic boil, impurities from the cotton, and materials produced by the partial break-down of the fiber. This kier liquor, with its dark brown persistent color, is the largest single waste from the cotton mills and has proven very difficult to treat.

Proximity Mill waste was a catch sample obtained from the waste-discharge line of that mill. Indigo and sulfur colors are the dyes used, hence the waste contained the discharges from those two dyes together with wash water.

Lagoon waste consisted of a variety of wastes discharged from the Proximity Print Works and indigo waste from the White Oak Mill, both in Greensboro, N. C.

Sewage-mixture was composited on the assumption that all waste discharged from the mills would be proportioned over 24 hours according to sewage flow and had the following composition:

	Per Cent by Volume
Sewage	80.63
Prox. Mill discharge	0.76
Kier waste	1.57
Sulfur	0.06
Lagoon	11.00
Water	5.98
	100.00

Wastes were obtained through the cooperation of the management and employees of the Proximity Manufacturing Company. Sulfur wastes were piped directly to the experimental station while other wastes were obtained in five gallon carboys.

Procedure and Apparatus

All of this work was conducted on a laboratory scale. A diagrammatic sketch of the stirring device for mixing and flocculating the samples is shown in Figure 1. The stirring machine consists of eight copper paddles, each paddle having an area of 2 in. by 1 in., which were rotated by means of an electric motor. For mixing, the paddles were revolved at a speed of 242 r.p.m., and for flocculating at a speed of 77 r.p.m.

A series of beakers contained given volumes of waste. Varying amounts of reagent were added, and the mixtures were then stirred, flocculated, and settled. After one hour, floc formation and amount of floc produced were noted, pH was determined with a Coleman glass-electrode Electrometer, and color of the supernatant liquor was recorded. In many cases, these determinations were repeated after overnight settling. The entire pH range was investigated in the majority of cases by additions of reagents to the waste and by hydrogen-ion control with acid or lime. When two chemicals were used, and especially when pH adjustment was tried, the dosage of coagulant was varied over a wide range. An effort was made in all cases to exhaust the possibilities and thus obtain optimum conditions for coagulation.

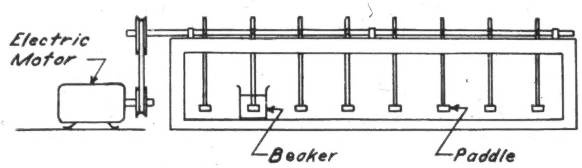

FIG. 1.—Stirring machine.

The chemicals used and their weights in pounds have been calculated for cost data F.O.B. Greensboro from the following formulas[9]:

Ferric Chloride	$FeCl_3 \cdot 6H_2O$	(Technical crystals—60% $FeCl_3$)
Ferric Sulfate	$Fe_2(SO_4)_3$	(90% $Fe_2(SO_4)_3$)
Copperas	$FeSO_4 \cdot 7H_2O$	(Crystals—bulk)
Caustic Soda	$NaOH$	(76% Na_2O)
Calcium Chloride	$CaCl_2 \cdot 2H_2O$	(Flaked)
Sulfuric Acid	H_2SO_4	(66° Bé.—94%, Sp. gr. 1.84)
Hydrochloric Acid	HCl	(20° Bé.—32%, Sp. gr. 1.16)
Lime	$Ca(OH)_2$	
Alum	$Al_2(SO_4)_3 \cdot 18H_2O$	
Copper Sulfate	$CuSO_4 \cdot 5H_2O$	

The chemicals were prepared as normal or tenth-normal standard reagents. The milk of lime suspensions contained either 25 grams or 2.5 grams of lime per liter. These standardized reagents were added from burettes to 100 ml. portions of thoroughly mixed wastes prepared in the manner later indicated. The treated samples were rapidly mixed for a period of 15 to 120 seconds, and permitted to flocculate for periods up to 30 minutes. The time required for such mixing and flocculating was dependent upon the type of waste and reagent used. The resulting mixture was transferred to 100 ml. short Nessler tubes and allowed to settle for one hour. At the termination of this settling period the following characteristics were recorded:

Ratio of sludge volume to supernatant liquor
pH of the supernatant liquor
Color of the supernatant liquor by comparison with platinum-cobalt standards.

In addition, many samples were allowed to remain overnight, an average of 18 hours, and sludge volumes, pH, and color noted again.

After completion of the settling tests, drainability of the samples was determined by means of the filtering apparatus shown in Fig. 2. An 11 cm. Buechner funnel with No. 202 Reeve-Angel, rapid filtering paper was used. In all cases, a vacuum of 22 in. of mercury was maintained by means of a tap aspirator in order to afford a means of correlating experimental results with those obtainable with the Oliver vacuum filter.

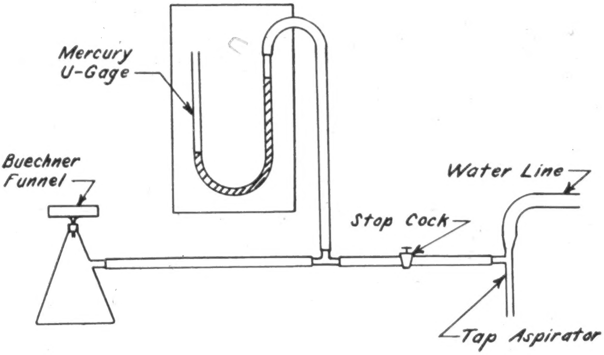

FIG. 2.—Filtering apparatus.

Criteria of Discharge.—A clear, water-appearing, neutral discharge is desirable from the treatment of all wastes, but with strong textile waste liquors complete purification by chemical means is not always feasible. Chrisco, White, and Baity[10] estimated that a color of 100 or less on the platinum-cobalt scale and a pH varying from 6.0 to 8.0 were satisfactory for discharge. In the present studies an attempt has been made to obtain these standards, but in many cases this has been economically infeasible, and, in the cases of pretreatment, may be entirely unnecessary.

RESULTS

Sulfur Dye Waste

Sulfur dye waste was obtained directly from the dye machines and had no wash water. It had a deep blue-black color, a pH of about 11.7, B.O.D. of approximately 20,000 p.p.m., and 7.44 per cent total solids of which 66 per cent was ash. One minute mixing, followed by twenty minutes flocculation was employed in this study. The various reagents used on this waste and the optimum conditions for their use have been summarized in Table I.

TABLE I.—*Summary of Results Obtained by Treating Sulfur Black Dye Waste with Optimum Amounts of Various Chemicals*

Reagents				pH	Color	Cost in $/1000 g. for Treatment	Filtering Time in Sec.	Remarks
First		Second						
Name	lb./1000 g.	Name	lb./1000 g.					
$FeCl_3$	150.6			8.3	400	3.24	80	
$Fe_2(SO_4)_3$	139.0			7.9	300	1.98		
$FeSO_4$	214.0			8.3	150	1.29	82	
HCl	262.0			4.2	100	3.02	10	H_2S
H_2SO_4	136.0			3.5	100	1.08	30	H_2S
$Al_2(SO_4)_3$	256.0			5.0	100	2.94	110	H_2S
$CuSO_4$	312.0			6.2	100	13.27	150	
$CaCl_2$					No Removal			Floc Formed
$Ca(OH)_2$					No Removal			
$FeCl_3$	60.2	HCl	181.0	4.1	100	3.375		H_2S
$FeCl_3$	15.1	H_2SO_4	109.0	3.7	80	1.224		H_2S
$Fe_2(SO_4)_3$	44.5	HCl	162.0	4.8	150	2.564	30	H_2S
$Fe_2(SO_4)_3$	44.5	H_2SO_4	65.4	5.9	150	1.244	17	H_2S
$FeSO_4$	92.8	HCl	152.6	4.1	100	2.308	17	H_2S
$FeSO_4$	58.0	H_2SO_4	87.2	4.6	100	1.068	51	H_2S
$Al_2(SO_4)_3$	111.6	H_2SO_4	65.4	4.3	150	1.825	80	H_2S
$CuSO_4$	83.2	HCl	143.0	4.4	200	5.178		H_2S
$CaCl_2$	24.6	$Al_2(SO_4)_3$	279.0	4.9	75	3.490	60	H_2S
$CaCl_2$		HCl			No Removal			

Discussion.—As can be noted, the best results were obtained with strong acids, alum, and copper sulfate, while copperas gave fair results. Of the various mixtures, ferric chloride and hydrochloric acid, ferric chloride and sulfuric acid, copperas and hydrochloric acid, copperas and sulfuric acid, and calcium chloride with alum, gave excellent color removal.

Strong acids were the most economical but the evolution of hydrogen sulfide prohibits their use in many cases. The effluent from acid treatment upon standing became very turbid because of the presence of colloidal sulfur. If the cleared supernatant liquor was allowed to stand overnight, the pH increased and the color had a tendency to return. When the pH was increased by the addition of caustic soda to approximately neutral, a strong color returned. This increase in color was noticeable even when the supernatant liquor was diluted with water; the pH was increased by the water. Color reappeared at as low a pH as 6.0.

Alum also causes the strong evolution of hydrogen sulfide, with the appearance of colloidal sulfur.

The iron and copper salts precipitated the waste without odors and produced a good effluent.

In an effort to reduce the quantities of iron salts required for coagulation, the pH was adjusted by acid. Other combinations were also tried, but the results were similar to those of previous runs where acid alone was used, with the exception that hydrogen sulfide and odor production were decreased. However, odors were sufficient to cause objections. In general, combinations were not economical, since acid alone produced similar results at lower cost.

As indicated in Fig. 3, the sludge settled very poorly in all cases, and, hence, dewatering was necessary. Accordingly, samples were dewatered by suction through a Buechner funnel. A good sludge cake was formed that dried rapidly and cracked; filtering times are shown in Table I.

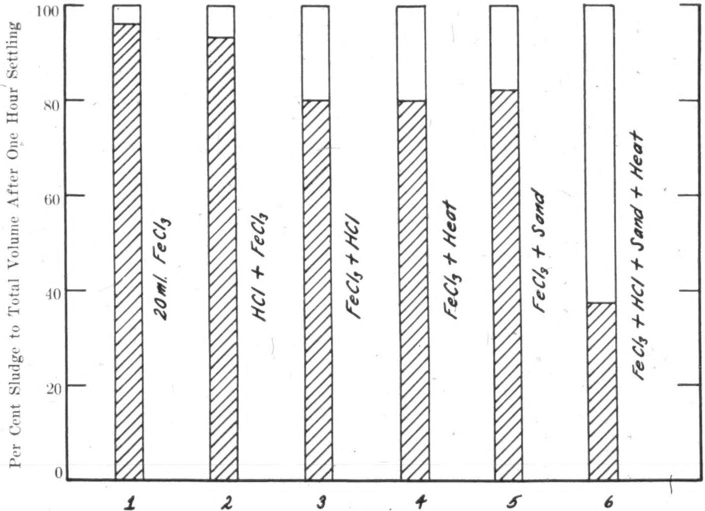

FIG. 3.—Graph showing sludge settling properties of sulfur dye waste under various treatments.

Similar results were obtained by Rudolfs and Baumgartner[11], who concluded that ferric chloride in conjunction with hydrochloric acid, or copperas in conjunction with sulfuric acid produced the most satisfactory effluent from sulfur black waste. They used 72 lb. of 95 per cent sulfuric acid per 1000 gallons as compared to the 136 pounds required in this study. However, the analyses of the wastes indicate that the present waste was much stronger. Chrisco, White, and Baity[10] concluded from their experiments with sulfur black waste that by using large quantities of acid, satisfactory color removal could be obtained but the resulting supernatant liquor would be objectionable because of the acidity and turbid appearance.

Conclusions.—Although sulfuric acid is the most economical chemical to clarify sulfur wastes, the hydrogen sulfide production and the resulting poor effluent, eliminate the use of this chemical. Copperas is the best coagulant and gives a clear supernatant liquor without the production of odors. Little or no pH adjustment for discharge is required as the final pH is 8.25, thus more than compensating for the slight additional first cost. The sludge produced appears to be amenable to filtration.

Additional Investigations with Sulfur Waste

Mixing and Flocculating.—The effect of various agents upon the mixing was then investigated. A dosage of 20 ml. of normal ferric chloride per 100 ml. sample gave consistent results. Mixing times were varied as follows: 15, 30, 45, 60, 75, 90, 105, and 120 seconds. Color, pH, and settling were noted.

While settling showed a slight tendency towards more compacting with the least amount of mixing, the residual color was very much the same in all cases, and the pH gave no consistent trends. Fifteen seconds was assumed as the mixing time advisable for proper contact between waste and reagent.

The periods of flocculation were then varied as follows: 0, 2, 5, 10, 15, 20, 25, and 30 minutes. Samples were settled one hour, at which time pH, color, and settling were recorded. No definite trends were obtained from either pH or color determinations. Settling tests showed that greater compacting resulted without flocculation, indicating that flocculation is not necessary and may be harmful.

Addition of Chemicals.—Acid was the first chemical added in those experiments requiring pH adjustment. If the addition of reagents was reversed, that is, the coagulant added first, the results were improved. The evolution of hydrogen sulfide and the resulting odors were subdued although not entirely eliminated; color removal improved and compacting was much better (Fig. 3).

Weighting.—The volume of sludge to be handled is most important in a chemical precipitation process. In an endeavor to reduce this volume and induce compacting, sludge was weighted with inert material. One hundred ml. samples of sulfur black waste were used and 20 ml. of ferric chloride added. The inert materials, china clay (aluminum silicate, $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$), coal dust, and sand were added along with the reagent.

Clay increased settling but color removal was poor, while coal dust and sand increased settling and also color removal.

Heat.—Textile wastes are discharged while hot and heat may affect treatment. A series was arranged with temperature increases in steps from room temperature to 102.5 degrees C. Twenty ml. of normal ferric chloride was used as the coagulating reagent. After one hour settling, sludge volume was recorded, and samples reheated to original temperatures and then filtered.

As can be noted in Table 1*A*, a sharp break in the settling rate occurred at 45° C., with the optimum at 65° C. In the case of filtering, TABLE 1*a*.—*Effect of Temperature Variations upon Settling and Dewatering of 100 ml. Sulfur Dye Waste Using 20 ml. Normal Ferric Chloride as Coagulant*

No.	Initial Temp. ° C.	Sludge Volume to Supernatant	Filtering Time in Seconds	Remarks
1	22.5	13 to 1	103	Room Temp.
2	25	10.5 to 1	83	
3	30	17 to 1	67	Before filtering samples were reheated to original temperatures.
4	35	10 to 1	88	
5	40	11 to 1	79	
6	45	8 to 1	37	
7	50	6 to 1	45	
8	55	6 to 1	43	
9	60	5 to 1	50	
10	65	4 to 1	37	
11	70	5 to 1	23	
12	75	7 to 1	31	
13	80	6 to 1	36	
14	85	4.5 to 1	24	
15	90	6.5 to 1	—	
16	95	4 to 1	26	
17	100	7 to 1	30	
18	102.5	8.5 to 1	26	Boiling Temp.

a sharp break occurred at 45° C., the filtering rate dropping from 79 sec. at 40° to 37 sec. at 45°. Above 45° C. little change in the dewatering rate was observed.

A group of tests were run at the optimum conditions, including combination of chemicals, their proper addition, 15 seconds mixing and no flocculation, temperature control, and weighting. The results are given in Table II; also given in the table, for comparison, is a run made with 20 ml. of ferric chloride at room temperature and using no weighting material.

TABLE II.—*Precipitation of Sulfur Black Dye under Optimum Conditions*

Reagents (1.0 N)				Temp. ° C.	Inert Material	Color	Sludge Vol. to Supern. Vol. in 1 hr.	Filtering Time in Sec.
First		Second						
Name	ml./100 ml.	Name	ml./100 ml.					
$FeCl_3$	8	HCl	19	65	2 gms. coal dust	75	1 to 1.7	29
$FeCl_3$	8	HCl	19	65	4 gms. sand	100	1 to 1.5	160
$Fe_2(SO_4)_3$	8	HCl	19	65	2 gms. coal dust	50	1 to 1.6	
$FeSO_4$	5	HCl	19	65	2 gms. coal dust	100	1 to 1.4	23
$Al_2(SO_4)_3$	10	HCl	17	65	2 gms. coal dust	250	1.9 to 1	48
$Al_2(SO_4)_3$	10	HCl	17	65	4 gms. sand	350	1.6 to 1	50
$FeCl_3$	20			22.5		400	1.3 to 1	80

Conclusions.—The optimum precipitation of sulfur black waste appears dependent upon mixing, flocculating, and addition of chemicals, especially when sludge settling is considered. A short rapid mix, followed by little or no flocculation, forms the most compact sludge when ferric chloride is the coagulant.

Addition of iron salts prior to the addition of acids, reduces odors and favors better color removal. This is probably due to the formation of insoluble iron sulfide from the sodium sulfide. The removal of sulfide by this method reduces the source of odors and also removes the solution agent of sulfur dyes, resulting in better color removal.

Weighting of the sludge to produce more rapid settling is advantageous when only a short settling period is available. By the addition of inert materials, such as coal dust or sand, complete settling is obtained in one hour that under ordinary conditions requires overnight or longer. Weighting may not be advantageous where long detention periods are available.

Kier Liquor

Kier liquor was obtained directly from the discharge line of the boilers. It had a pH of 11.8; color of about 10,000 p.p.m.; B.O.D., 8000 p.p.m.; total solids, 2.69 per cent, of which 36.1 per cent was ash; total alkalinity, about 1 per cent. The coagulating reagents were added to 100 ml. samples which were rapidly mixed for 1.0 minute, flocculated 20 minutes, and then settled.

Discussion.—Floc was formed in all cases with the exception of acids and lime. Some color removal was obtained with alum, copper sulfate, copperas, and calcium chloride, while other reagents produced negligible results.

Combinations of reagents were next investigated upon kier liquor which was weaker than the first batch; as analysis showed 0.6 per cent total alkalinity and 5,000 p.p.m. color. Thirty seconds mixing and 5 minutes flocculation were used, as determined by experimentation with alum and lime. A summary of results is given in Table III.

Iron salts, with the exception of a combination of copperas and lime, gave poor results; the latter produced an effluent with a color of 300 p.p.m. at a reasonable cost. Alum alone and in conjunction with other chemicals gave good results, especially the combination with copper sulfate, which produced an excellent-appearing effluent. However, one disadvantage of alum was a reduced filtering rate.

Copson and Curtis [12] developed a process of carbonation, utilizing stack gas and then precipitating with calcium chloride. A similar process was tried upon two samples of kier liquor. Carbon dioxide was generated and introduced into the kier waste until all hydroxides were transformed into carbonates. Bicarbonates were determined by titration and enough kier liquor added to convert the bicarbonates to carbonates. Precipitation of the carbonates was then induced by the addition of calcium chloride. A color of 600 p.p.m. was obtained, indicating that this process may be satisfactory for partial removal. Cost data on the amount of calcium chloride used are given in Table III.

The second kier liquor processed by carbonation was boil-out waste, containing 6.2 per cent total alkalinity, 17,500 p.p.m. color, and having a pH of 11.38. With 12.5 grams of calcium chloride per 100 ml. of carbonated waste, an effluent with a color of 1250 was obtained. Sludge settled rapidly and filtered in 2 min., 10 sec. A sludge composite filtered in 2 min., 55 sec., producing a beautiful cake over ⅛ in. thick. Fourteen grams of alum with this waste produced an effluent with 500 p.p.m. color. Sludge did not settle but filtered in 4 min., 30 sec., forming a very dry cake 1/16 in. thick.

TABLE III.—*Summary of Results Obtained by Treating Kier Liquor with Optimum Amounts of Various Chemicals*

Reagents				pH	Color	Cost in $/1000 g. for Treatment	Filtering Time in Sec.
First		Second					
Name	lb./1000 g.	Name	lb./1000 g.				
$Al_2(SO_4)_3$	130.2			5.0	100	1.498	No break in 5 min.*
H_2SO_4		$FeCl_3$		Unsatisfactory			
$Ca(OH)_2$	12.6	$FeCl_3$	105.3	7.7	800	2.339	
$Ca(OH)_2$		$Fe_2(SO_4)_3$		Unsatisfactory			
H_2SO_4		$FeSO_4$		Unsatisfactory			
$Ca(OH)_2$	12.6	$FeSO_4$	145.0	9.2	300	0.938	
H_2SO_4	8.7	$Al_2(SO_4)_3$	111.7	5.2	200	1.357	
$Ca(OH)_2$	12.6	$Al_2(SO_4)_3$	148.9	6.1	200	1.781	
$CaCl_2$	30.3	$Al_2(SO_4)_3$	111.7	6.2	250	1.637	No break in 5 min.*
$Al_2(SO_4)_3$	83.7	H_2SO_4	6.5	6.1	200	1.124	No break in 5 min.*
$Al_2(SO_4)_3$	27.9	$CuSO_4$	104.0	6.0	200	4.741	
H_2SO_4		$CaCl_2$		Unsatisfactory			
$Ca(OH)_2$	12.6	$CaCl_2$	158.3	11.6	350	1.834	
$Ca(OH)_2$	12.6	$CuSO_4$	156.0	6.7	100	6.699	
CO_2		$CaCl_2$	73.8	9.5	600	0.847†	

* Composite samples filtered.

† Does not include cost of CO_2.

Chrisco, White, and Baity[10] determined that copperas and lime offered possibilities of successful treatment, while Campbell[13] found calcium chloride, alum or copperas unsuitable for coagulation of kier. Hadley[14], experimenting with waste from the bleach house, used alum and lime to obtain good results, but found that the filtering of sludge was not very successful. This is in accordance with results of the work being reported. Hadley found that sludge responded to earth drying.

Conclusions.—For the treatment of kier liquors, alum alone, or alum and acid, produced the best results at low cost. Copperas and lime yielded fair results with an effluent having a color of 300 p.p.m.; this is the most economical combination. Carbonation by carbon dioxide and coagulation with calcium chloride produced a poor effluent but offers possibilities as a cheap method for partial clarification. This latter method should find use with exceptionally strong kier liquors.

Indigo Waste

Indigo waste liquor was obtained from the discharge line of the White Oak Mill, Greensboro, N. C. It had a greenish-blue appearance, color of 3500 p.p.m., and pH of 10.5. A summary of results obtained by treating indigo with various chemicals for a mixing time of 30 sec. and flocculating time of 5 min., is shown in Table IV.

TABLE IV.—*Summary of Results Obtained by Treating Indigo Waste with Optimum Amounts of Various Chemicals*

Reagents				pH	Color	Cost in $/1000 g.		Filtering Time in Sec.
First		Second						
Name	lb./1000 g.	Name	lb./1000 g.			for Treatment	for Final pH Adj.	
$FeCl_3$	7.5			8.7	450	0.162		
$Fe_2(SO_4)_3$				Unsatisfactory				
$FeSO_4$				Unsatisfactory				
$Al_2(SO_4)_3$	93.0			4.2	200	1.070		100
$CaCl_2$	154.0			8.2	200	1.765		
$Ca(OH)_2$	41.8			11.8	125	0.230	0.195	
$FeCl_3$		H_2SO_4		Unsatisfactory				
$FeCl_3$	4.5	$Ca(OH)_2$	12.5	11.5	250	0.166	0.079	35*
$Fe_2(SO_4)_3$		H_2SO_4		Unsatisfactory				
$Fe_2(SO_4)_3$	2.8	$Ca(OH)_2$	41.8	11.8	250	0.274		
$FeSO_4$	5.8	$Ca(OH)_2$	12.5	11.5	200	0.104	0.065	25*
$Al_2(SO_4)_3$	27.9	H_2SO_4	1.6	6.7	250	0.335		
$Al_2(SO_4)_3$	74.4	$Ca(OH)_2$	12.5	6.5	250	0.925		
$Al_2(SO_4)_3$	27.9	$CaCl_2$	49.2	6.3	250	0.886		
$Ca(OH)_2$	12.5	$CaCl_2$	61.5	11.6	200	0.775		
$CaCl_2$		HCl		Unsatisfactory				
$CuSO_4$				Unsatisfactory				
CO_2		$CaCl_2$	18.5	9.4	300	0.212†		

* Composite samples filtered.

† Does not include cost of CO_2.

Discussion.—Lime was the best and most economical of the individual chemicals, producing an effluent with a color of 125 p.p.m. Copperas and lime showed the most promising results of all the mixtures. The overall cost of copperas and lime, including the adjustment of the effluent to pH 8.0 by means of sulfuric acid, was the lowest. Alum and calcium chloride produced fair results. A good rate of compacting was experienced with all except the alum sludge; however, alum sludge filtered and dried in 1 min. 40 sec. Other sludges filtered very rapidly.

Mixing and flocculating periods, using alum as coagulant, showed that only minimum periods were necessary. Another series was performed with lime and copperas as reagents and varying flocculating times from 0 to 30 minutes. Lime was added and mixed, then copperas added and mixed. The following compilation shows that at least 30 min. is advisable for flocculation and possibly a longer period may prove advantageous.

Conditions	Lime and Copperas							
Flocculating Period (Min.)	0	1	2	5	10	15	20	30
Residual Color	1200	600	600	500	500	350	350	250

A most interesting group illustrating the effect of additions, mixing, and flocculating periods, is shown in Table V. Best results were obtained when lime was added first and mixed, then copperas added and mixed, followed by flocculation. A flocculation period of 30 min. would have produced better results according to the previous tabulation. As illustrated in the eighth sample, it is unnecessary to mix the lime if sufficient contact time is allowed. These results are comparable to those obtained by Campbell[13] and by Chrisco, White, and Baity[10]. The former determined that copperas and lime gave highest reduction in color. Calcium chloride was recommended because the final pH of the effluent made it satisfactory for discharge. The latter also concluded that copperas and lime produced most satisfactory color removal, with alum alone as second choice.

TABLE V.—*Effect of Variations in the Application of Reagents to Indigo Waste*

Reagent Added First	Mixed 30 sec.	Reagent Added Second *	Flocculated 5 min.	Time Between Additions	pH	Sludge Vol. to Supern. 1 hr.	Color in 1 hr.		Sludge Vol. to Supern. 24 hr.
							p.p.m.	Appearance	
$Ca(OH)_2$	Yes	$FeSO_4$	Yes	0	11.5	1 to 4.7	400	Light Green	1 to 5.7
$Ca(OH)_2$	Yes	$FeSO_4$	No	0	11.5	1 to 5.2	1000	Cloudy Green	1 to 6.1
$FeSO_4$	Yes	$Ca(OH)_2$	Yes	0	11.5	1 to 7.7	1200	Blue-green	1 to 10.0
$FeSO_4$	Yes	$Ca(OH)_2$	No	0	11.5	1 to 8.1	2000	Dark Blue	1 to 10.0
$Ca(OH)_2$	No	$FeSO_4$	Yes	0	11.5	1 to 4.9	700	Light Green	1 to 6.1
$FeSO_4$	No	$Ca(OH)_2$	Yes	0	11.5	1 to 6.1	2000	Blue	1 to 7.7
$Ca(OH)_2$	No	$FeSO_4$	Yes	30 sec.	11.5	1 to 4.1	500	Light Green	1 to 5.7
$Ca(OH)_2$	No	$FeSO_4$	Yes	10 min.	11.5	1 to 4.9	400	Light Green	1 to 5.7
$FeSO_4$	No	$Ca(OH)_2$	Yes	30 sec.	11.5	1 to 6.4	2000	Dark Blue	1 to 7.7
$FeSO_4$	No	$Ca(OH)_2$	Yes	10 min.	11.5	1 to 7.3	1500	Blue-green	1 to 9.0
$Ca(OH)_2$ and $FeSO_4$ mixed, then added to waste			Yes		11.5	1 to 8.1	625	Light Green	

* All mixed 30 seconds.

Conclusions.—Best color removal from indigo waste liquor was obtained with lime, next best with alum, and third best with calcium chloride. The most economical choice is the combination of lime and copperas, even though adjustment of the final pH by means of sulfuric acid is necessary. The order of adding the chemicals and the time allowed for mixing and for flocculating are most important. For example, lime must be added first, followed by a mix, then copperas added, mixed, and the composite flocculated for at least 30 minutes. The resulting sludge dewatered rapidly, forming a dry cake.

Vat Dye Waste

Vat blue liquor was obtained from the color box of the dyeing machine. It had a pH of 11.7, B.O.D. of about 2000 p.p.m., 15,000 p.p.m. total alkalinity, and 2.54 per cent total solids of which 87 per cent was ash. The mixing period was set at 30 seconds and flocculating period at 5 minutes. The results obtained by treating such a vat waste are shown in Table VI.

TABLE VI.—*Summary of Results Obtained by Treating Vat Dye Waste with Optimum Amounts of Various Chemicals*

Reagents				pH	Residual Color	Cost in $/1000 g. for Treatment
First		Second				
Name	lb./1000 g.	Name	lb./1000 g.			
$FeCl_3$	105.4			9.7	500	2.265
$Fe_2(SO_4)_3$	94.5			9.1	500	1.497
$FeSO_4$	116.0			11.0	250	0.697
HCl				Unsatisfactory		
$Al_2(SO_4)_3$	232.5			6.3	250	2.675
$CuSO_4$	166.3			9.7	600	7.080
$CaCl_2$				Unsatisfactory		
$Ca(OH)_2$				Unsatisfactory		
$FeCl_3$	60.2	H_2SO_4	34.8	9.6	500	1.584
$FeCl_3$	90.4	$Ca(OH)_2$	12.5	10.3	400	2.014
$FeSO_4$	69.6	H_2SO_4	43.6	8.8	500	0.778
$FeSO_4$	92.8	$Ca(OH)_2$	12.5	11.1	300	0.625
$Al_2(SO_4)_3$	74.4	H_2SO_4	65.4	6.4	400	1.396
$Al_2(SO_4)_3$	186.0	$Ca(OH)_2$	12.5	8.9	500	2.209
$CaCl_2$		HCl		Unsatisfactory		
Vat Wash						
$Fe_2(SO_4)_3$		$Ca(OH)_2$		Unsatisfactory		
$FeSO_4$	46.4	$Ca(OH)_2$	14.6	10.7	75	0.359
$Al_2(SO_4)_3$		$Ca(OH)_2$		Unsatisfactory		
$CuSO_4$	83.2	$Ca(OH)_2$	20.9	7.1	100	3.651

Copperas, alum, and copperas in combination with lime, gave best results. On a cost basis, copperas and copperas-lime combination showed the most promise. It was not economical to reduce the color below 250 p.p.m.

Experiments on the order of addition of reagents proved that copperas or ferric chloride should be added first. No difference could be noted when alum and lime were used together; but acid should be added before alum.

As the vat bath is seldom dumped, another sample of waste was composited from the continuous overflows from the wash boxes and had a pH of 6.73, with 1550 p.p.m. total alkalinity, and 125 p.p.m. acidity. This was treated with the chemicals indicated in Table VI, and again copperas and lime proved most efficient.

Conclusions.—Vat dye wastes are difficult to treat but are relatively unimportant because of the small volumes discharged. The main waste is obtained from the continuous discharges from the wash boxes. Copperas alone gave good results, while copperas and lime combined were the best reagents and also the most economical.

Direct Dye Waste

The direct blue waste obtained from the dye house had a pH of 10.8 and 6.58 per cent total solids of which 62 per cent were ash. This waste was treated with various chemicals by mixing for 30 sec. and flocculating for 5 min. The results are presented in Table VII.

TABLE VII.—*Summary of Results Obtained by Treating Direct Blue Waste with Optimum Amounts of Various Chemicals*

Reagents				pH	Residual Color	Cost in $/1000 g. for Treatment
First		Second				
Name	lb./1000 g.	Name	lb./1000 g.			
$FeCl_3$	3.4			3.5	150	0.073
$Fe_2(SO_4)_3$	2.8			3.6	250	0.044
$FeSO_4$				Unsatisfactory		
H_2SO_4				Unsatisfactory		
$Al_2(SO_4)_3$	7.4			4.3	250	0.086
$CuSO_4$	10.4			5.8	250	0.442
$CaCl_2$				Unsatisfactory		
$Ca(OH)_2$				Unsatisfactory		
$FeSO_4$	3.5	$Ca(OH)_2$	52.3	11.9	100	0.309
Another Batch of Waste						
$FeCl_3$	120.5	$Ca(OH)_2$	73.2	10.4	250	2.990
$Fe_2(SO_4)_3$	111.2	$Ca(OH)_2$	94.1	10.1	350	2.277
$FeSO_4$	69.6	$Ca(OH)_2$	25.1	8.5	200	0.554
$FeSO_4$	208.8	$Ca(OH)_2$	77.3	10.7	125	1.678
$Al_2(SO_4)_3$		$Ca(OH)_2$		Unsatisfactory		
$CuSO_4$		$Ca(OH)_2$		Unsatisfactory		

Ferric chloride was the most efficient and ferric sulfate was the cheapest of the reagents used. Only a small amount of sludge was produced and this settled rapidly. Clarification was obtained at a very low pH.

A much stronger waste with a pH of 8.0 was used when the effects of combinations of coagulants were studied. Copperas and lime proved the most efficient and economical.

Conculsions.—Ferric chloride alone and copperas in combination with lime produced the most satisfactory effluent from direct dye waste. The most economical reagent was ferric sulfate which produced a good effluent. Only a small quantity of sludge was produced, which settled rapidly.

Developed Color Waste

Developed blue waste was secured from the dye house. As this dye has three main wastes, equal volumes of each were mixed to produce the proper composite. The three wastes are obtained (1) from the dye vat containing a direct dye in water and having a pH of 8.40, (2) from the diazotizing vat containing sodium nitrite and sulfuric acid and having a pH of 1.70, and (3) from the developing vat containing beta-naphthol and caustic soda and having a pH of 11.80. The mixture gave a resulting pH of 3.3, a B.O.D. of about 2000 p.p.m., 3.44 per cent total solids with 95.3 per cent ash. A summary of the results with chemical treatment including 30 sec. mixing is shown in Table VIII.

TABLE VIII.—*Summary of Results Obtained by Treating Developed Blue Waste with Optimum Amounts of Various Chemicals*

Reagents				pH	Residual Color	Cost in \$/1000 g. (for Treatment
First		Second				
Name	lb./1000 g.	Name	lb./1000 g.			
$FeCl_3$				Unsatisfactory		
$Fe_2(SO_4)_3$				Unsatisfactory		
$FeSO_4$				Unsatisfactory		
$Al_2(SO_4)_3$				Unsatisfactory		
$CuSO_4$				Unsatisfactory		
$CaCl_2$				Unsatisfactory		
$Ca(OH)_2$				Unsatisfactory		
NaOH				Unsatisfactory		
$FeCl_3$		$Ca(OH)_2$		Unsatisfactory		
$Fe_2(SO_4)_3$	18.3	$Ca(OH)_2$	10.5	7.0	350	0.348
$FeSO_4$	11.6	$Ca(OH)_2$	2.1	5.6	150	0.081
$Al_2(SO_4)_3$		$Ca(OH)_2$		Unsatisfactory		
$CaCl_2$		$Ca(OH)_2$		Unsatisfactory		

It is noteworthy that the addition of single reagents resulted in no color removal, while of the combinations, copperas and lime gave the best results both from standpoint of color removal and cost, and ferric sulfate and lime was only fair. The method of adding the reagents was then investigated and it was found that copperas added first, followed by a quick mix, then by the addition of lime and mixing, gave best results. Sludge compacting was very good. Flocculation studies with copperas and lime indicated that better color removal resulted with minimum flocculation. Similar results were reported by Chrisco, White, and Baity [10], who indicated that copperas and lime, and ferric chloride and lime gave the best results on wastes from developed black.

Conculsions.—In the treatment of developed color waste, the best and most economical results were obtained from copperas and lime. It is important that the iron salt be added first, mixed, then followed by lime and mixed.

Naphthol Color Dye Waste

The naphthol waste consisted of a mixture from two vats; one contained naphthol, caustic, and some penetrating oil, the second held the dye. The resulting mixture had a pH of 11.6, a color of 22,500 p.p.m., and a russet appearance. All samples were mixed for 30 sec. and flocculated for 5 minutes. Table IX contains a summary of the results of treating this waste.

TABLE IX.—*Summary of Results Obtained by Treating Naphthol Dye Waste with Optimum Amounts of Various Chemicals*

Reagents: First: Name	Reagents: First: lb./1000 g.	Reagents: Second: Name	Reagents: Second: lb./1000 g.	pH	Residual Color	Cost in $/1000 g. for Treatment	Cost in $/1000 g. for Final pH Adj.	Filtering Time in Sec.
$FeCl_3$	33.9			5.6	100	0.729		
$Fe_2(SO_4)_3$	27.8			5.0	100	0.440	0.012	
$FeSO_4$	52.2			7.0	350	0.312		
H_2SO_4	21.8			4.5	140	0.180	0.012	30*
$Al_2(SO_4)_3$	55.8			4.5	100	0.642	0.012	10*
$CuSO_4$	62.4			5.9	125	2.650		
$CaCl_2$				Unsatisfactory				
$Ca(OH)_2$				Unsatisfactory				
$FeCl_3$	33.9	$Ca(OH)_2$	2.1	8.2	160	0.741		59*
$Fe(SO_4)_3$	27.8	$Ca(OH)_2$	3.6	8.0	175	0.636		
$FeSO_4$	52.2	$Ca(OH)_2$	4.2	9.5	250	0.336		
$Al_2(SO_4)_3$	55.8	$Ca(OH)_2$	3.1	6.4	90	0.659		

* Composite samples filtered.

Good results were obtained with the precipitation of the naphthol dye waste with individual reagents. Ferric chloride, ferric sulfate, sulfuric acid, alum, and alum and lime combination, gave good results. Sulfuric acid was the cheapest, with copperas second in price, although color removal was incomplete. In all cases sludge settled poorly but dewatered rapidly.

Lack of sufficient waste prevented the completion of the study with mixtures of chemicals; however, indications point to a reduction in cost.

Conclusions.—Sulfuric acid provided the cheapest treatment for naphthol dye waste. Ferric sulfate, alum, and ferric chloride also produced excellent effluents but at an increased cost.

Aniline Black Wash Water

Aniline black wash water was obtained from the wash boxes and is comparable to the continuous discharges from the machines. It had a pH of 6.5, 50 p.p.m. alkalinity, 30 p.p.m. acidity, B.O.D. of about 900 p.p.m., and color of about 500 p.p.m. It was light pink in color with a cloudy appearance. Samples were mixed for one minute and flocculated for five minutes. A summary of results of chemically treating this wash water is given in Table X.

TABLE X.—*Summary of Results Obtained by Treating Aniline Black Dye Wash with Optimum Amounts of Various Chemicals*

Reagents				pH	Residual Color	Cost in \$/1000 g. for Treatment
First		Second				
Name	lb./1000 g.	Name	lb./1000 g.			
$FeCl_3$	1.5	$Ca(OH)_2$	0.6	7.7	80	0.036
$FeSO_4$	2.3	$Ca(OH)_2$	0.6	6.9	100	0.017
$Al_2(SO_4)_3$	0.9	$Ca(OH)_2$	0.4	7.0	80	0.013
$CuSO_4$	2.1	$Ca(OH)_2$	0.4	6.5	60	0.091
$Ca(OH)_2$	6.3			11.7	100	0.035

Conclusions.—The ease with which lime and lime in conjunction with other chemicals clarified this liquor eliminated the necessity for further investigation. Very satisfactory results were obtained with alum and lime, and as this combination costs the least, it is first choice.

Proximity Mill Waste

Waste from the Proximity Mill was obtained from the discharge line leaving the plant, and consisted of the overflow from indigo and sulfur raw stock dyeing. The waste appeared yellowish-green in color with tendencies towards a blue on the surface due to oxidation, and had a pH of approximately 10.0.

The results of treatment on such a waste are shown in Table XI. As in the previous tests, reagents were added to the samples, which were then mixed for 30 seconds and flocculated for 5 minutes. Lime alone gave good results at the lowest cost. Good results were obtained, also, with alum, copperas and lime combination, and calcium chloride. According to True[15], this waste has been treated with calcium chloride.

Conclusions.—For the treatment of the Mill waste consisting of the overflow from indigo and sulfur raw stock dyeing, lime surpasses the other chemicals tried, but good results were obtained also with alum, copperas and lime, and calcium chloride.

Lagoon Waste

Lagoon waste secured from the outlet end of the dye pond appeared grayish blue and had a pH of approximately 6.30. The treatment with reagents was carried out as in the earlier tests. The most promising results were given by lime alone and lime in conjunction with other chemicals; these are summarized in Table XII. Copperas and lime were most economical, with alum and lime as second choice as to cost. It has been reported by True[15] that alum and acid gave best results with

TABLE XI.—*Summary of Results Obtained by Treating Proximity Mill Waste with Optimum Amounts of Various Chemicals*

Reagents				pH	Residual Color	Cost in $/1000 g. for Treatment
First		Second				
Name	lb./1000 g.	Name	lb./1000 g.			
$FeCl_3$				Unsatisfactory		
$Fe_2(SO_4)_3$				Unsatisfactory		
$FeSO_4$	13.9			8.0	500	0.084
HCl				Unsatisfactory		
H_2SO_4				Unsatisfactory		
$Al_2(SO_4)_3$	37.2			6.2	125	0.428
$CuSO_4$				Unsatisfactory		
$CaCl_2$	24.6			8.7	225	0.282
$Ca(OH)_2$	20.9			11.6	200	0.115
$Ca(OH)_2$	52.3			11.8	150	0.288
$Fe_2(SO_4)_3$		H_2SO_4		Unsatisfactory		
$Fe_2(SO_4)_3$		$Ca(OH)_2$		Unsatisfactory		
$FeSO_4$	17.4	$Ca(OH)_2$	12.5	11.4	150	0.173
$Al_2(SO_4)_3$		H_2SO_4		Unsatisfactory		
$Al_2(SO_4)_3$		$Ca(OH)_2$		Unsatisfactory		
$CaCl_2$		H_2SO_4		Unsatisfactory		
$CaCl_2$	61.5	$Ca(OH)_2$	12.5	11.4	250	0.775
$Al_2(SO_4)_3$		$CaCl_2$		Unsatisfactory		

this waste. It is probable that with a higher initial pH, acid instead of lime in conjunction with alum, as reported in this work, would give best results. Settling offered no difficulty when precipitating this waste.

TABLE XII.—*Summary of Results Obtained by Treating Lagoon Waste with Optimum Amounts of Various Chemicals*

Reagents				pH	Color	Cost in $/1000 g.	
First		Second					
Name	lb./1000 g.	Name	lb./1000 g.			for Treatment	for Final pH Adj.
$Ca(OH)_2$	4.2			11.5	100	0.023	0.032
$Ca(OH)_2$	20.9	$FeCl_3$	3.8	11.9	125	0.196	
$Ca(OH)_2$	2.9	$Fe_2(SO_4)_3$	1.7	10.6	150	0.043	
$Ca(OH)_2$	1.3	$FeSO_4$	3.5	9.7	100	0.034	0.003
$Ca(OH)_2$	1.3	$Al_2(SO_4)_3$	5.6	5.0	100	0.071	
$Ca(OH)_2$	2.1	$CuSO_4$	10.4	6.2	100	0.454	
$Ca(OH)_2$	2.1	$CaCl_2$	8.6	10.8	100	0.110	

Conclusions.—Excellent results are obtained when treating lagoon waste with lime, copperas and lime, and alum and lime.

Sewage Waste Mixture

Sewage was pumped to the experimental plant from the main outfall sewer of the city of Greensboro, N. C. Waste was mixed with the sewage in proportions estimated to approximate the mixture that would occur if all wastes from the mills were discharged into the sewer. Daily sewage flow and lagoon discharge data were obtained from E. H. Moss, Superintendent of the North Side Activated Sludge Plant of the City of Greensboro. Mill discharge data were obtained from a report by the N. C. State Board of Health [16], from A. O. True, sanitary engineer for the mills, and from investigations conducted by the authors. The pH of the mixture varied from 7.4 to 8.9; this variation was caused by differences in the pH of the sewage. The color of the mixture varied from 350 to over 600 and on occasions was much higher.

TABLE XIII.—*Summary of Results Obtained by Treating a Sewage-Waste Mixture with Optimum Amounts of Various Chemicals*

Reagents				pH	Residual Color	Cost in $/M.G.	
First		Second					
Name	lb./M.G.	Name	lb./M.G.			for Treatment	for Final pH Adj.
$FeCl_3$	4518			4.8	70	97.20	
$Fe_2(SO_4)_3$	5004			3.8	80	79.20	
$FeSO_4$				Unsatisfactory			
$CuSO_4$	3120			7.1	125	132.60	
$Al_2(SO_4)_3$	930			7.4	150	10.70	
$Al_2(SO_4)_3$	2790			6.9	70	32.10	
$CaCl_2$				Unsatisfactory			
$Ca(OH)_2$	209			8.7	150	1.15	0.81
$Ca(OH)_2$	2926			10.8	80	16.10	11.22
$FeCl_3$	2259	$Ca(OH)_2$	1254	8.6	100	55.50	
$Fe_2(SO_4)_3$	1668	$Ca(OH)_2$	1254	8.9	80	33.30	
$FeSO_4$	2320	$Ca(OH)_2$	1672	9.3	90	23.12	
$CaCl_2$	2460	$Ca(OH)_2$	4180	10.9	80	51.24	

Results of treating such a sewage waste mixture with chemicals are shown in Table XIII. Preliminary flocculation studies with alum indicated that a one-minute mix, followed by ten-minute flocculation, gave the optimum conditions. When another reagent was used in conjunction with lime, the former was added, then lime, followed by one-minute mixing and ten-minute flocculation.

Conclusions.—The final choice of treatment will depend upon its cost, and lies with copperas and lime, lime, alum, or ferric sulfate and lime. An effluent satisfactory for discharge must be close to neutral, hence it is important when considering cost to include the added cost for pH adjustment. Another point of consideration is the amount of color toleration in the effluent. As indicated in Table XIII, the cost of treatment, especially with lime, may be reduced tremendously if an effluent with a color of 150 p.p.m. were acceptable.

The resulting volume of sludge was not excessive. The sludge appeared only as a trace and settled rapidly.

In precipitating this waste with two reagents, lime was added second. Rudolfs and Gehm [17], experimenting on additions of chemicals to sewage, concluded that best results were obtained when lime was added first and then the ferric iron; when acid and iron were used, the iron should be added first, followed by acid. It appears, therefore, that the order of adding chemicals depends on characteristics of the waste and will vary according to conditions. This has been illustrated throughout the present study.

Conclusions.—Lime, copperas and lime, alum, or ferric sulfate and lime, gave good results at lowest cost in the treatment of sewage waste mixture. The final choice will depend upon local cost of chemicals and upon the color removal required.

It is important to investigate the addition of chemicals and their order of addition in order to obtain the proper selection for satisfactory treatment.

Discussion

Hydrogen-ion concentration is undoubtedly an important control factor in the successful precipitation of any waste. It was believed that the pH curves constructed from pH data obtained by the addition of increments of reagents to the waste would indicate the significant zones of color removal, maximum precipitation, and possibly the isoelectric point. Two groups of such curves for sulfur dye waste and kier liquor have been plotted in Figs. 4 and 5. In general, the curves

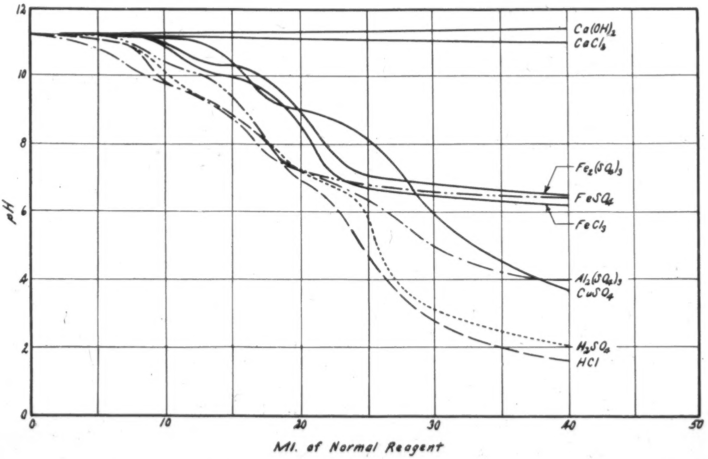

FIG. 4.—Graph showing relation of pH and increments of various reagents added to 100 ml. of sulfur black dye waste.

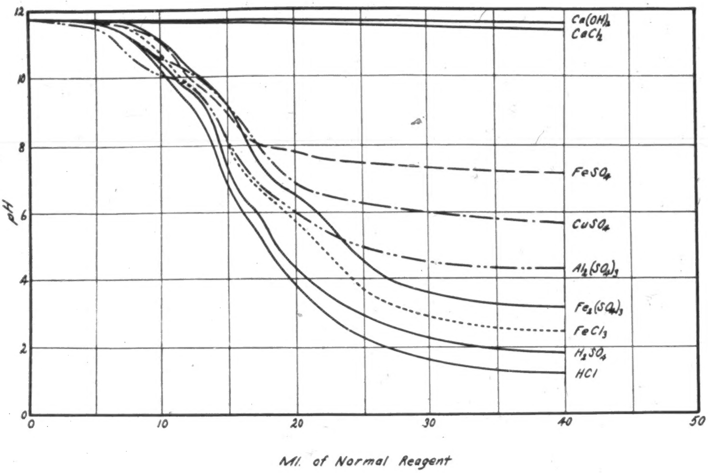

FIG. 5.—Graph showing relation of pH and increments of various reagents added to 100 ml. of kier liquor waste.

give an indication of the action of the chemicals. Noticeable clarification is absent and poor floc formation occurs in the region indicated by the straight portions at the beginning of the curves. The first drop in the curves corresponds, in general, to the beginning of floc formation with color removal. This is true in all cases using iron salts, alum, and copper sulfate. The main point of inflection, that is, the change of slope in the major portion of the curve, gives an indication of the optimum pH zone for precipitation.

In many cases, data for such curves may be obtained without much color removal although floc formation is usually obtained; a condition that occurred with kier liquor waste. In another instance, calcium chloride produced a floc with sulfur dye waste without pH change. However, neither calcium chloride nor lime removed color, and, as illustrated in Fig. 4, no break in the pH curves of these two chemicals is evident. Concentrated wastes, such as sulfur and kier, give rather definite inflection points while dilute wastes give curves having long slanting slopes with no sharp inflection points. It is possible that with a great deal of experience, many pH curves may be interpreted. However, the uncertainty showed that, as yet, definite conclusions can not be drawn from these pH curves and applied directly to treatment studies, and that the problem should be approached from another angle. The possibilities of using pH curves in conjunction with conductometric titrations are being investigated. The study appears promising and will be reported in a future contribution.

Table XIV.—*pH Zone for Optimum Clarification with Dye Wastes Treated by Various Reagents*

Reagents	Sulfur	Kier	Indigo	Vat	Direct	Developed	Naphthol	Aniline	Proximity Mill	Lagoon	Sewage Waste Mixture
$FeCl_3$	8.3	9.8/4.8	8.7	9.7	3.5		5.6				4.8
$Fe_2(SO_4)_3$	7.9	4.3		9.1	3.6		5.0				3.8
$Al_2(SO_4)_3$	5.0	6.4	6.0	6.3	4.3		4.5		6.2		6.6
HCl	4.2	3.8					4.5				
H_2SO_4	3.5	4.0									
$CuSO_4$	6.2	6.8			5.8		5.9				
$FeSO_4$	8.3	8.0		10.0			7.0		7.9		
$CaCl_2$		11.5	8.2						8.7		
$Ca(OH)_2$			11.8					11.7	11.6		10.8
$FeCl_3$ & $Ca(OH)_2$		7.7	11.5	10.3	10.4		8.2	7.7		11.7	8.6
$Fe_2(SO_4)_3$ & $Ca(OH)_2$		9.2	11.6		10.1	7.0	8.1			10.6	8.9
$Al_2(SO_4)_3$ & $Ca(OH)_2$			6.5				6.4	7.0		6.2	
$CuSO_4$ & $Ca(OH)_2$				7.1				6.5		6.2	7.0
$FeSO_4$ & $Ca(OH)_2$		9.2	11.5	11.2	8.5	5.6	9.5	6.9	11.4	8.2	9.3
$CaCl_2$ & $Ca(OH)_2$		11.6	11.6						11.4	10.8	9.9
$FeCl_3$ & HCl	4.1			9.6							
$Fe_2(SO_4)_3$ & HCl	4.8										
$Al_2(SO_4)_3$ & HCl	4.3	6.1		6.4							
$CuSO_4$ & HCl	4.4	6.7									
$FeSO_4$ & HCl	4.1			8.8							
$CaCl_2$ & HCl											
$FeCl_3$ & H_2SO_4	3.7										
$Fe_2(SO_4)_3$ & H_2SO_4	5.9										
$Al_2(SO_4)_3$ & H_2SO_4		6.1	6.7								
$CuSO_4$ & H_2SO_4											
$FeSO_4$ & H_2SO_4	4.6										
$CaCl_2$ & H_2SO_4											
$CaCl_2$ & CO_2		9.5	9.4								

The pH at which optimum conditions for clarification of wastes were obtained are summarized in Table XIV. pH values obtained by the addition of single reagents were not always within the optimum range but at that value at which color removal was acceptable. Usually in those cases, better results were obtained more economically by pH adjustment. Color removal was the criterion in all cases except kier liquor waste, which gave little indication of color removal. However, floc formation with ferric chloride gave interesting results which have been plotted in Fig. 6. These data indicate two optimum pH zones of floc formation: one from pH 9.7 to 11.4, and the other from pH 3.2 to 5.0. Very little floc is formed from pH 6.5 to 8.5. This is in exact accordance with the results of Bartow, Black, and Sansbury[18], who experimented with water and determined that between a pH of 6.5 and 8.5 there is a zone in which ferric floc forms slowly or not at all.

A titration curve for ferric chloride with a sulfur khaki dye waste is given in Fig. 7, and shows these two zones by pH variations and checks closely with the results obtained with kier. Previous curves with ferric chloride did not show this because of the greater strength of the waste and varying buffer actions of the mixtures. Thus ferric chloride has two zones where optimum precipitation may be expected.

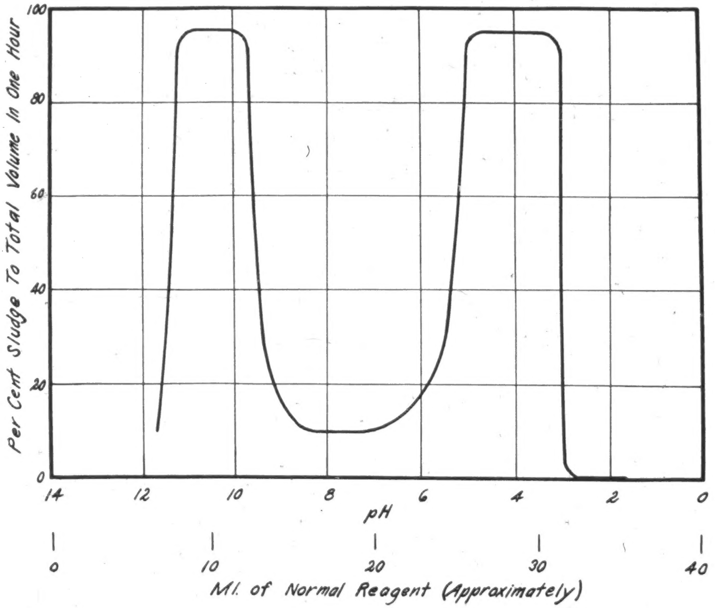

FIG. 6.—Graph showing sludge volume obtained by flocculating kier liquor with ferric chloride.

According to actual precipitation studies shown in Table XIV, one zone lies above pH 8.0 and the other below pH 5.5. With pH adjustment, best results were obtained in the alkaline range. Slight variations from these values may be expected with industrial wastes having large quantities of suspended and dissolved solids. This is often due to inefficient mixing and delayed action of the coagulants.

Ferric sulfate exhibited zones of optimum precipitation similar to those of ferric chloride.

Copperas appears to precipitate waste at pH values above pH 8.0. A slight variation from this zone was observed in one case where an acid waste was treated. It is probable that this variation was the result of ionization of the precipitant (soluble in acid range), thus yielding high valent ions that may neutralize the electrical charges on colloidal particles and cause them to aggregate and settle. Therefore, such variations from the theoretical may not be optimum points but may be the economical points. It is probable that better color removal will be obtained at the optimum pH zone but at a greater cost. As economics is a vital factor, this is an important consideration in waste treatment.

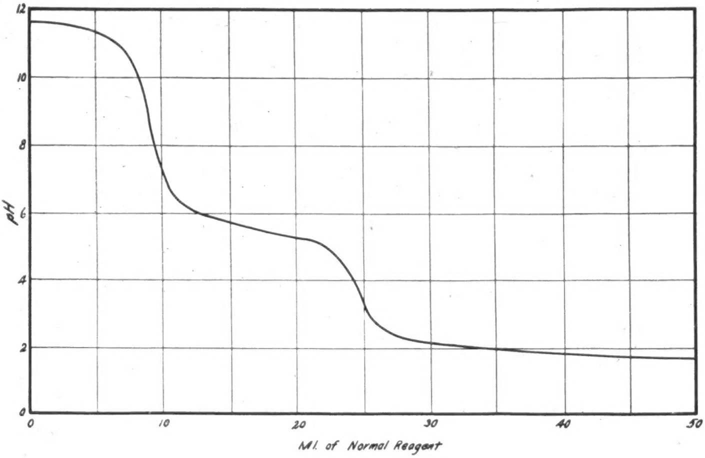

FIG. 7.—Graph showing relation of pH to increments of ferric chloride added to 100 ml. sulfur khaki waste.

The alum range was rather definite, being within the limits of pH 6.1 to 7.0. The optimum point of clarification was approximately pH 6.5.

Copper sulfate also showed a narrow range of activity from pH 6.2 to 7.1, with optimum at about pH 7.0.

Calcium chloride worked at high pH values in most cases; the lowest being 8.2.

Lime was most efficient at very high pH values; the lowest value was approximately pH 10.0 but the majority were above pH 11.5.

Acids produced precipitation best at a low pH range, usually below pH 5.0. In the case of mixtures of salts with acids, the pH zone approximated that of the acid. It is believed that in these cases the acid radical of the salt was utilized as an aid in pH control as similar results were obtained with acid alone at a much lower cost.

The close correlation between the chemicals used and the pH zone of precipitation is most striking and appears to be independent of most of the wastes treated. Other work shows similar correlations. Chrisco, White, and Baity [10], experimenting with a variety of wastes obtained final pH values approximating the zones determined by this study. Whedbee and Zeller[19], experimenting with sewage, concluded that ferric chloride reacted at pH 5.5; alum at pH 6.0 to 8.5; copperas at pH 9.0 or above; and calcium chloride on the alkaline side. Hopkins[20] states that coagulation with iron and lime is most efficient at pH values of about 9.0; while Steel and Zeller[21], treating dairy waste, found that acid was most efficient at pH 4.0 to 5.5.

These data covering water, sewage, and industrial wastes show that close correlation exists between the chemical and the pH zone for maximum clarification. As it is then possible under most conditions to determine the pH zone at which to expect coagulation and maximum clarification for the coagulant used, the problem accordingly simplifies itself into means and methods of obtaining sufficient coagulant to obtain coagulation at the optimum pH zone.

The procedures will vary with the individual wastes. If sufficient alkalinity is present, the addition of the coagulant alone may result in the optimum pH zone and provide sufficient coagulant for efficient precipitation. With acid wastes, lime or lime in combination with another coagulant will give best results. It will be necessary in the majority of cases to control pH with acid or lime according to the conditions of the waste. The use of acid as coagulant, or for pH adjustment with dye waste, is sometimes advantageous from the point of quantity of sludge produced, as acids may not produce a floc but may throw out the dye by pH adjustment. When used in conjunction with a coagulant, acid properly employed for pH adjustment results in the minimum requirements of coagulant and a minimum of sludge.

The treatment of textile wastes is a difficult problem because of the many variables encountered. It has not been feasible to exhaust all possibilities and obtain the best precipitating condition but rather it has been the aim of the authors to indicate those factors that influence efficient precipitation. The successful treatment of industrial wastes will necessitate competent operation of treatment plants under personnel qualified to tackle the problem as the variation in the daily composition of wastes necessitates constant experimentation. Personal contacts with pioneers in the field of textile waste disposal have shown that in many cases less efficient chemicals are still being employed although improvements in the methods of dyeing in the mill have varied the discharge to such an extent that more economical precipitants could be used.

The cost of treating strong discharges such as textile wastes is very high. It may be advantageous, however, to treat a small volume of strong wastes at a high unit cost rather than a large volume of waste, or sewage and waste, at low unit cost. In those mills where separation of strong wastes from wash waters is practical, the possibility of treating the strong discharges more economically than the combined wastes should be investigated. Pretreated wastes may be successfully treated in many instances by the municipal disposal plant without undue hardship. Where dilution is sufficient, such a waste may be properly disposed of by discharging into the stream or other waters. Satisfactory color removal and from 80 to 85 per cent reduction in B.O.D. can be obtained. The resulting B.O.D. from the treatment of strong wastes will be high but after mixing and diluting with the large volumes of wash waters, the composite waste should not exert a large pollutional load. The B.O.D. reduction obtained by treating the sewage-waste mixture with alum, resulting in the final color below 100, was from 70 to 75 per cent.

It appears, in general, that the ultimate solution of textile waste disposal lies not in one method but rather in a combination involving chemical and biological means. Chemical treatment of textile wastes may be employed to remove color, adjust pH, and remove the heavy B.O.D. load, and so transform the liquor to a form amenable to biological treatment.

pH adjustment of the supernatant liquor for discharge is an important factor in the chemical treatment of wastes. Waste liquor or effluents discharged into waterways should be near neutral, that is, within the pH limits 6.0 to 8.0. This standard was adhered to in these studies wherever pH adjustment was investigated. The expense of pH adjustment should be included in cost data for chemical treatment as pH adjustment is part of the process of preparing the waste for final discharge. The added expense of pH adjustment often influences the choice of coagulant. In the cases where pretreatment is practical, it may not be necessary to adjust the final pH, especially should the supernatant be alkaline. Many operators find that alkaline wastes discharged into sewers are beneficial in the treatment of sewage and aid sludge digestion.

The chemicals used in the precipitation of textile wastes will probably vary according to the waste received. In general, copperas and lime will react most satisfactorily with this group of wastes and will probably be the most economical coagulants to employ. The order in which the chemicals should be added is very important and should be determined, as great improvements in the results may occur by the proper handling of the coagulants.

Proper mixing and flocculating should be determined, as they appear at times to be important factors. Sludge compacting is influenced by mixing and flocculation, and as large sludge volumes are one of the main disadvantages of chemical precipitation, these factors should be investigated.

Another factor which affects sludge volumes is the treatment of hot wastes as discharged from the mill. Compacting of sludge and rates of dewatering increase with a warm waste. Weighting of sludge with heavy material appears to offer additional possibilities as a means of reducing the volume of sludge produced in the precipitation of textile wastes, although it is well to remember that the addition of inert material increases the weight of the sludge to be handled. Sludge compacting is very important should the retention periods be short. With long detention times, such as 24 hours, all sludges tend to reach maximum compaction.

Conclusions and Summary

Various types of textile wastes were treated with various individual chemicals and combinations of chemicals. Investigations were made to determine the coagulants best adapted for the precipitation of textile wastes, and methods of applying the chemicals; pH range for coagulation by these reagents; and any correlation between pH zone and the coagulant used.

Chemicals were added to representative samples of textile wastes, and the mixtures were then stirred, flocculated, and settled for one hour, after which color of supernatant, pH, and sludge volume were recorded.

Results of this study show that the chemicals that produce optimum precipitation will vary according to the waste. In general, copperas and lime offer the best possibilities from the standpoints of efficiency and economy of precipitation. It has been shown that results are radically improved in many cases by the proper handling of chemicals, such as order of addition of reagents and time of mixing and flocculating. These factors must always be investigated. Sludge compacting is also influenced by the order of adding chemicals. In cases where a dense sludge is formed, compacting may be hastened by weighting with an inert material and by heat. Heating sulfur black dye waste to 65° C. rapidly increased both settling and dewatering of the sludge.

The control of hydrogen-ion concentration offers the best control factor for efficient operation of a chemical precipitation plant. Variations in individual textile wastes and in types of textile wastes appear to have little effect upon optimum precipitation range. In general, results show that each coagulant appears to have a pH zone for optimum precipitation and this zone should be obtained by the addition of reagent or usually, better still, by the adjustment of pH by means of acid or lime. In spite of the wide variations of wastes treated, there is remarkable correlation between the chemical used, pH, and optimum precipitation. It appears feasible, then, to precipitate wastes at stated pH values depending upon the coagulant used, thus eliminating one important variable. It appears that greater use should be made of pH data in chemical precipitation.

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Discussion by C. M. Nichols

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I have read the copy of Mr. Porges' paper with very great interest and I feel that the author should be complimented on the scope of the data presented and the systematic manner in which the possibilities of the numerous chemicals available for chemical precipitation have been studied.

I was fortunate enough to have the opportunity to visit the experimental laboratory at Greensboro, North Carolina, last year with several other engineers from our department and was impressed with the unusual facilities provided there for studies on this particular phase of the industrial wastes problem.

The data gathered should be of great benefit to the whole industry, not only in North Carolina but in other states which have similar problems. The technical staffs of the state health departments are faced with such a multiplicity of tasks that, in most cases, they must limit their activities, because of lack of appropriations, time or facilities, to the duties placed upon them by the police powers under which they function; that is, they must insist on the discharge of an effluent of a certain quality but are not in a position to carry out extensive investigations, to determine how such effluents can be produced at the least cost per gallon of wastes treated.

Mr. Porges' paper deals with the experimental treatment of industrial wastes by means of chemical precipitation and the magnitude of the problem confronting the industry and the State Department of Health in North Carolina is indicated by the estimate of 430 textile mills discharging 59,000,000 gallons of wastes per day.

The problem facing the State Department of Health in New Jersey, in relation to the discharge of this type of wastes, is not of such magnitude and is controlled by the location of the mills, the nature and usage of the receiving waters, and the acts of legislature under which the Department operates.

A great majority of the textile mills in New Jersey are located on the watersheds of the lower Hackensack River, the lower Passaic River, and the lower Delaware River, all of which are tidal waters.

A smaller number of mills are located upon intrastate streams, the waters of which are later used, after sufficient treatment and purification, for public potable water supply purposes. Into the disposal of wastes from mills so located, enters the provisions of the act adopted by the legislature in 1921, which requires that all industries desiring to locate thereafter on a potable watershed must first obtain a license from the State Department of Health; also, the act of 1899, relating to the purity of public water supplies, commonly known as the Potable Water Act, and the State Sewerage Act, passed the same year.

The aforesaid Potable Water Act prohibits the discharge of certain polluting matters including factory, workshop, and mill wastes, as well as dye-stuff, into waters later used for potable purposes. But the State Sewerage Act, passed the same year, requires that before sewage and other polluting matter are discharged into the state waters, such matter shall be treated in a manner which is satisfactory to the State Department of Health. Based on an opinion of our Court of Errors and Appeals, it is concluded that these two laws go hand in hand.

The experience of our Bureau of Engineering with a textile wastes treatment plant treating approximately 2,000,000 gallons of wastes daily, located upon the watershed of one of our largest municipalities, will, I believe, be of interest to this gathering. This textile plant started operations in the early 1890's, prior to the use of the watershed for public potable purposes and prior to the passage of the act requiring a license from the State Department of Health to so locate.

The plant is located about 13 miles above the water intake reservoir, on an upland stream, having an average daily run-off of 50,000,000 gallons and a minimum run-off of 10,000,000 gallons per day.

The processes consist of the bleaching, dyeing, printing, and finishing of cotton cloth. The cloth as received at the mill is washed to remove the size, boiled in kiers with soda ash and caustic soda, drained, rinsed, treated with a sodium hypochlorite solution, then a weak sulfuric acid solution. This completes the bleaching operation. The kier liquors and first rinse are coffee brown in color, have a high pH, contain heavy concentrations of mineral and organic matter in solution, and are very difficult to treat.

The bleach-house wastes, exclusive of the kier liquors and first rinse, are generally of a milky appearance ranging in reaction from neutral to slightly alkaline, and contain considerable amounts of lint. Although not concentrated, they represent, on account of their large volume, a very considerable amount of oxygen demand.

The colors used in the printing and dyeing process are mainly aniline dyes of the basic, rapidogen and vat groups. To render the several dyes effective, hydrosulfites, organic acids, soda ash, caustic soda and other chemicals, including considerable quantities of starch, are used in the process. Following the printing and dyeing, the cloth is subjected to a soaping process to remove any loose color from the meshes of the cloth, and finally, in the finishing process, starch, as well as various other reagents such as sulfonated oils, talc, waxes and stearic acid, are used.

Prior to 1926, the entire industrial wastes from the plant were discharged into lagoons and thence to the river. In that year, following complaints concerning the effect of the wastes upon the receiving waters, devices for the addition of chemicals and settling tanks were installed. Enlargements to the settling basins were installed in 1934 but, in spite of this fact, complaints continued concerning the deleterious effect of the wastes on the quality and appearance of the stream waters. Investigations by the State Department of Health led to a threat to enforce the provisions of the aforesaid Potable Water Act unless steps were taken to eliminate the causes of complaint.

Following this action, a series of conferences were held, before the Director of the Department, between the officials of the textile plant and the municipality, and these resulted in the formulation of the following set of standards governing the effect of the wastes discharge:

1. That there will be no increase in the *B. Coli* content of the waters of the Rockaway River, at or below said works, over that content of the said river immediately above the said works.
2. That the dissolved oxygen in the waters of the Rockaway River, below the premises of the said works, shall not drop below five and five tenths parts per million (5.5 p.p.m.) or below sixty per cent (60%) saturation; provided, however, that if the per cent saturation of the river waters above the premises of the said works drops below ninety per cent (90%) saturation, the per cent saturation of the river waters below the premises of the said works shall be not less than fifty per cent (50%) saturation.
3. That the increase in the biochemical oxygen demand of the waters

of the Rockaway River, due to the discharge or storage of wastes from said works, shall not cause a reduction of the dissolved oxygen content of the waters of the said river lower than that amount of dissolved oxygen specified under the aforementioned requirement number 2, not only at the specified sampling point or station, but at any point or station below.

4. That the hydrogen-ion concentration, in the waters of said river, shall remain in the brom thymol blue range (that is a range of from 6.0 to 7.6); provided, however, that if a variation greater than said range occurs in the waters of the Rockaway River above the premises of said works, nothing shall be added from said works that will tend to increase said hydrogen-ion concentration.
5. As not to substantially discolor or add to the turbidity of the waters of the Rockaway river; result in the production of oil or grease on the surface of the said river; render the appearance of the river objectionable to the sight, or, produce sludge banks, of a putrescible nature in the bed of said river; and further, in the matters of works operation and works supervision:
6. That the point of chlorine application shall be so established as to give, as a minimum, a one-half hour detention period even under maximum waste flow; and, that the amount of chlorine applied, at all times, shall be sufficient so as to give not less than one part per million (1 p.p.m.) of residual chlorine in the treatment plant effluent at the point of discharge of said effluent into the receiving waters of the said Rockaway River; and, that the apparatus for the application of the aforementioned chlorine shall be so housed as to insure efficient and continuous operation through all variations in temperature and weather conditions.
7. That the disposal, treatment and/or purification of the wastes or other polluting matter shall be under efficient and satisfactory laboratory control; further, that such laboratory control shall include the daily performance of the necessary tests that will furnish information upon the conditions established under the above-mentioned requirements one, two, three, four, five and six; and further, that a monthly record of these tests performed and the results obtained in said tests shall be submitted to the Department of Health of the State of New Jersey; and further, in the matters of the collection and examination of samples from the said Rockaway River:
8. That the sampling point or station below the premises of the said works shall be about five hundred (500) feet below the lowest, that is downstream, point from which wastes or other polluting matter are discharged into the waters of the said Rockaway River.
9. That the performance of the necessary tests shall be made in conformity with Standard Methods for the examination of Water and Sewage, eighth edition, as prepared, approved and published

jointly by the American Public Health Association and the American Water Works Association.

As a result of the adoption of these standards in 1937, the company completed extensive enlargements and betterments to the treatment plant in 1938.

Early difficulties with the chemical treatment of the dye-house wastes resulted largely from the very great and rapid variation in both the quantity and quality of the wastes discharged to the treatment plant, therefore, in the 1938 additions to the treatment facilities, an equalizing tank was installed into which the entire day's volume of dye-house wastes are discharged. Additional mixing of the contents is provided by revolving paddles and a circulating pump.

The dye wastes are pumped from the equalizing tank to a mixing tank having a theoretical detention of 30 minutes, at the entrance to which they receive the chemical dosage. The dye wastes treatment plant, designed to handle a dye wastes flow of 90,000 gallons in a 12-hour operating period, was handling 60,000 gallons of waste at the time the plant was tested. To this volume of wastes, a dosage of 225 pounds of alum and 150 pounds of lime was applied, or 26 and 17½ grains per gallon, respectively. From the mixing basins, in which air is used for stirring, the wastes are conveyed to twin settling tanks with hopper bottoms, having a detention period of 3½ hours based on a rate of flow of 90,000 gallons per 12-hour operating period.

As the wastes leave the settling basins, chlorine in solution is applied at a rate of 175 pounds per 12 hours. After chlorination, the treated dye wastes discharge by gravity to the head of the bleach-house raceway where they mix with the bleach-house wastes exclusive of the kier liquors and first rinse. Prior to 1938, the bleach-house wastes, amounting to 1 to 2 M.G.D., including the strong kier liquors and first kier rinse, had discharged without treatment through a small pond or lagoon in the raceway and thence direct to the stream. Under the operating program adopted in 1938, the kier liquor and first rinse are discharged into a concrete basin and from thence are pumped to the new sludge pits and are, therefore, kept out of the stream. The pond or lagoon in the raceway has been increased in capacity by raising the dam and is used as a chlorine detention tank for the combined dye and bleach house wastes amounting to a total of 1 to 2 M.G.D. The dosage of chlorine applied is sufficient to furnish a residual of 1 to 2 p.p.m. in the combined wastes as discharged to the stream. From the dam at the lower end of the chlorine detention tank, the wastes are returned through a 24 in. pipe into a manhole from which the wastes are distributed evenly across the width of the stream in the following manner: an 18 in. concrete pipe is laid in the river bed from bank to bank, approximately 50 ft., with 4 in. openings spaced 4 ft. apart at an angle of 45° to the vertical on the downstream face of the pipe. Small quantities of residual color and turbidity remaining in the wastes after treatment are completely lost in the total stream flow.

This latter feature is of considerable importance, as formerly, when the dye wastes were discharged directly at the bank of the stream and the bleach-house wastes discharged through the raceway along the same bank, about 500 ft. below, slime growths and sludge deposits were in evidence for a distance of 300 ft. below the bleach-house raceway and the dye hugged the bank so that it could be plainly seen for a distance of 1500 ft. below the point of discharge. These objectionable features were heightened by the location of a road bridge over the stream just a few hundred feet below the bleach-house raceway. Although it is true that the major portion of the improvement is due to more effective treatment resulting from changes made in the plant at the same time the outfall across the stream was constructed, it is believed that part of the benefits derived from the present treatment is due to the thorough and rapid mixing of stream water and wastes, which permits full use of the oxygen in the stream for the absorption and oxidation of the wastes.

Some idea of the improvement effected in the wastes effluent and the stream itself, as a result of the completion of the alterations and additions to the wastes treatment plant in 1938, can be obtained from the following comparison of analyses run.

Comparative Analyses of Wastes Discharge

	B. Coli per c.c.	Oxygen Consumed P.p.m.	Color	Turbidity	pH
Before new construction (dye)	1,000	884	125	72	4.2–7.0
Before new construction (bleach)	5,000	80	100	56	6.7
After new construction (combined)	0	54	35	47	6.3

Comparative Analyses of the River Below the Point of Wastes Discharge under Similar Stream Flow Conditions

Before new construction	100	17.1	40	10	7.05
After new construction	0	5.6	2	0	6.40

The analyses show that the wastes as discharged have a very appreciable oxygen demand; however, with the dilution afforded and the abundance of oxygen available, it is not expected that any difficulty will be encountered in meeting the standards set up for the stream just so long as the present degree of treatment is maintained.

Among the important changes made in the treatment processes in 1938 was the exclusion of the kier liquors and first rinse from the stream. These wastes had formerly been discharged in a batch in the early morning hours into the bleach-house raceway and thence to the stream.

As before mentioned, these strong wastes are now pumped, together with the sludge from the dye waste settling tanks, to gravel pits excavated with a steam shovel on property belonging to the company, adjacent to the plant. These pits are sufficiently far removed from the stream as not to constitute a menace. Two of these pits, which were dug in 1935, are about full and two more are being excavated at the present time.

It is believed that the adoption of these standards has given the manufacturer the assurance that the industry will not be coerced unnecessarily and has also given the interested municipality confidence that the manufacturing operations on the watershed will not adversely affect the quality of the water supply.

In conclusion, it is believed from experience gained in New Jersey and from the valuable data presented in the paper of Mr. Porges and his colleagues, that textile wastes treatment problems can be solved in whole or in part by the method of chemical precipitation.

It is also concluded that pH control is an outstanding factor in the successful use of such a method.

DIGESTION STUDIES ON PAPER PULP

By Milton T. Hill

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The satisfactory disposal of wastes resulting from the manufacture of paper and pulp has long been a problem to the sanitary engineer, as the common practice of discharging these wastes into nearby streams has resulted in the serious pollution of many watercourses.

The paper manufacturing industry, in cooperation with the departments of health of various states, has made marked progress during the past few years in eliminating much of the nuisance caused by the discharge of fibrous wastes into streams. This has been accomplished by the introduction of methods for reclaiming much of the fibrous material which was formerly wasted. The "Howard Process" for reclaiming pollutional substances in sulfite wastes, for which an efficiency of 75 per cent or better in reduction of B.O.D. is reported, is an outstanding example of development in this field.

It has been suggested that the treatment of paper or pulp mill wastes with domestic sewage might be an economical method of disposal. As the disposal of the sludge is one of the important factors in the design and operation of a sewage treatment plant, it was considered desirable to determine what effect pulp fibers would have on the digestion of sewage sludge in a separate sludge digestion tank. In order to obtain this information a study was conducted in the Sanitary Engineering Laboratory of the School of Civil Engineering at Cornell University, Ithaca, New York.

Equipment and Materials

Eight experimental digestion units of the battery of sixteen shown in Figs. 1 and 2 were used. Each unit consisted of two 55-gallon steel drums arranged as shown in Fig. 3. These digestion units had been used previously by Dr. W. L. Malcolm in studies on the digestion of ground garbage, and by Professor C. L. Walker in studies of the effect of activated carbon in sewage sludge digestion. The results of these studies were published in *This Journal* in Volume IX, page 389 (May, 1937) and in Volume IX, page 207 (March, 1937).

An average temperature of 81° F. was maintained in the room in which the digesters were kept by a thermostatically controlled steam unit heater. This temperature was the average of readings taken daily from two thermometers located in the vicinity of the digesters. The highest and lowest daily readings recorded were 83° F. and 78° F.

The fresh sewage sludge and the digested sewage sludge were obtained from the City of Ithaca Sewage Treatment Plant. The fresh sludge was taken from the measuring pit prior to pumping to the digestion tank, and the digested sludge used for seeding was taken from the sludge digestion tank. The fresh sewage sludge was delivered to the laboratory at the University in 40-quart milk cans three times each week. The paper pulp used was received in the form of lap stock which was made by the sulfite process and which was ground, after being thoroughly saturated with water, in a General Electric domestic garbage grinder.

Procedure

Prior to seeding the digestion tanks a thorough investigation was made to insure against any leaks in the units. This was done by forcing water into the drums used to collect the gas after all the outlets had been closed and the drums used as digesting tanks had been half filled with water. The air in each unit was thus compressed and pressures were created upon the water in the digestion tanks. This caused the water levels in the gauge glasses to rise. If after standing for twenty-four hours there was no drop of the water level in the gauge glass a unit was considered to be tight against the leakage of any gas or liquid. As soon as a unit was found to be both water and gas tight, the digestion tank was seeded with approximately 250 lb. of digested sewage sludge. This was followed by the addition of 5 lb. of fresh sewage sludge daily until all the units had been placed into operation and all were producing on February 11th the same amount of gas daily as

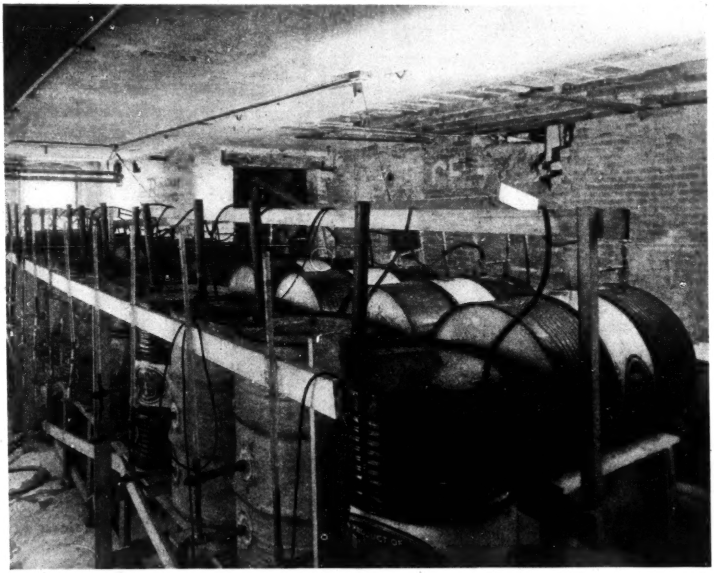


Fig. 1.

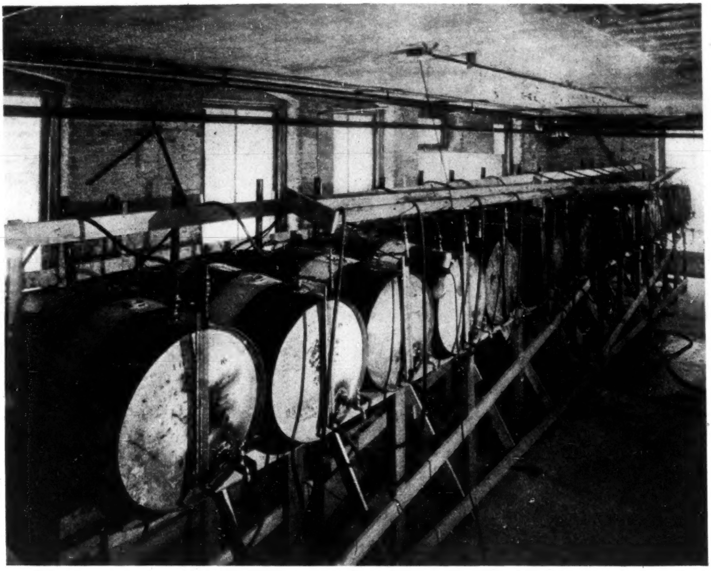


Fig. 2.

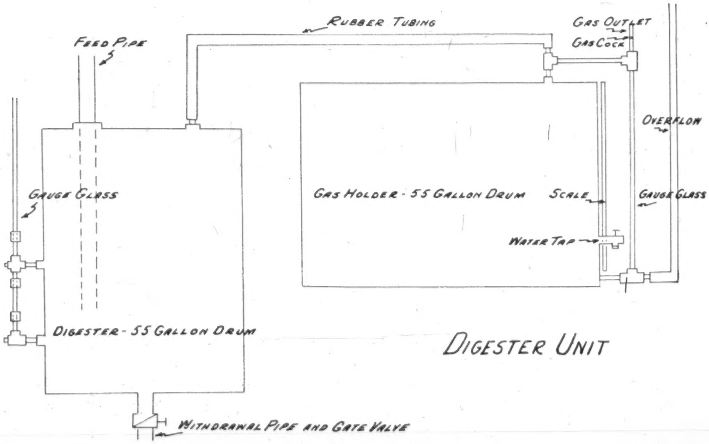

Rubber Tubing
Feed Pipe
Gas Outlet
Gas Cock
Overflow
Gauge Glass
Gas Holder - 55 Gallon Drum
Scale
Gauge Glass
Water Tap
Digester - 55 Gallon Drum
Digester Unit
Withdrawal Pipe and Gate Valve

Fig. 3.

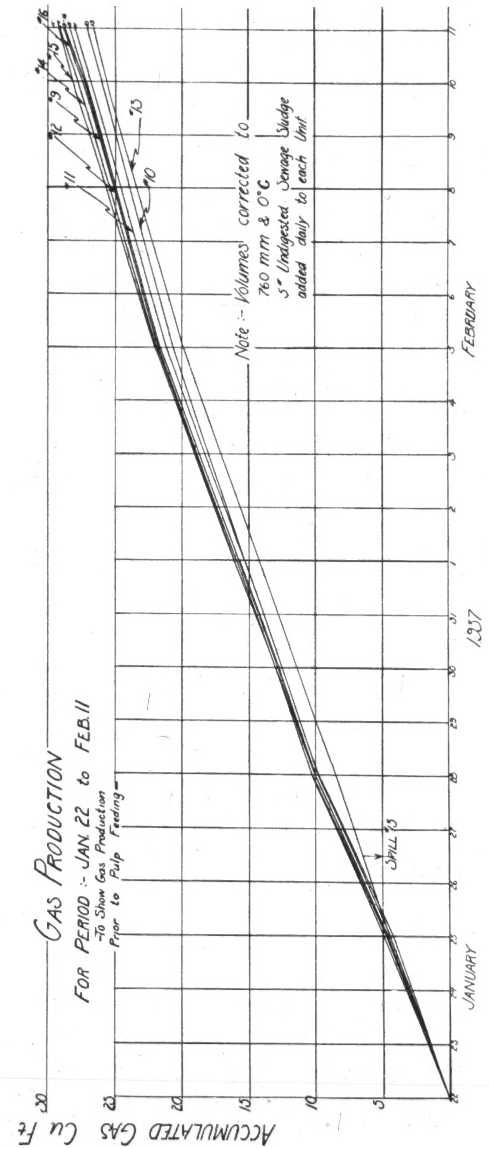

GAS PRODUCTION
FOR PERIOD :- JAN. 22 to FEB. 11
-To Show Gas Production Prior to Pulp Feeding-
Note :- Volumes corrected to 760 mm & 0°C
5" Undigested Sewage Sludge added daily to each Unit.
SPILL 15
ACCUMULATED GAS Cu Ft
30
25
20
15
10
5
22
23
24
25
26
27
28
29
30
31
1
2
3
4
5
6
7
8
9
10
11
JANUARY
FEBRUARY
1937
9
10
11
12
13
14
15
16

FIG. 4.

shown in Fig. 4. On the above date, when pulp feedings were started, all of the digesters had been in operation for periods of from 20 to 35 days. Thus, there was built up a well developed digestive activity, a substantial amount of bacterial food, and an environment to which the bacteria were acclimated before any paper pulp was added to the tanks.

During this period tests were run and quantities recorded of the sludge and supernatant removed, of the fresh sludge added, and of the gas withdrawn from each of the units. This was done in order that a fairly accurate estimate could be made of the volatile solids that remained in the digestion tanks at the time the pulp feedings were started, as shown in Table I. The volatile solids remaining in the tanks when the pulp feedings were started was calculated by dividing the cubic feet of gas produced by each digester, prior to the addition of pulp, by the average of the cubic feet of gas produced per pound of volatile solids digested during the entire operation of the two units, 9 and 10, to which no paper pulp was added. The average amount of gas produced by these two units was 16.5 cu. ft. per pound of volatile solids digested.

TABLE I.—*Summary of Operation of Digestion Units During Preliminary Period When No Paper Pulp Was Added.*

Unit	Date when unit was placed in operation 1936	Pounds of volatile solids (dry) in digested sludge used to seed tank	Pounds of volatile solids (dry) in fresh sludge added to tank	Pounds of volatile solids (dry) in digested sludge & supernatant removed from tank	Total cu. ft. of gas produced
9	12/18	15.33	7.17	4.45	64.50
10	12/21	14.33	6.85	3.39	61.05
11	12/22	11.22	6.72	3.49	62.90
12	12/12	10.00	7.70	4.01	41.78*
13	12/10	20.50	7.81	4.24	66.48
14	12/7	12.37	8.36	5.18	75.92
15	12/12	14.80	7.79	4.73	72.43
16	12/15	10.69	6.86	3.12	57.42

After all the units had been placed in operation, feedings of mixtures of the paper pulp and fresh sewage sludge to six of the digesters, and feedings of undiluted fresh sewage sludge to two of the digesters, were started. These feedings were continued daily except Sunday for a period of 64 days. Gas was measured and withdrawn at intervals of from 3 to 4 days, and at various times during the study a complete analysis of the gas produced by each digester was made. Sludge and supernatant were drawn when the level of the supernatant in the gauge glasses attached to the digesters reached a height near the top of the glasses. This required the removal of sludge or supernatant from each tank at weekly intervals. All of the sludge withdrawn or added to the tanks was tested for pH and for total and volatile solids. Carbon and nitrogen contents of three different samples of the fresh

Unit	Date when unit was placed in operation 1936	Cu. ft. of gas produced per lb. of (dry) volatile added to tank	Cu. ft. of gas produced per lb. of (dry) volatile solids added after seeding of tank	Pounds of volatile solids (dry) remaining in tank when pulp feedings were started
9	12/18	2.87	8.99	14.14
10	12/21	2.88	8.91	14.09
11	12/22	3.51	9.36	10.64
12	12/12	*	*	*
13	12/10	2.35	8.52	20.06
14	12/7	3.66	9.08	10.95
15	12/12	3.21	9.29	13.47
16	12/15	3.27	8.37	10.95

* Unit 12 was found to be leaking shortly after being placed into operation. Some of the gas, therefore, was lost before the leak was discovered and repaired.

sewage sludge and two different samples of the paper pulp were determined. From these analysis the different ratios of carbon to nitrogen of the mixtures of fresh sludge and paper pulp fed to the units was calculated (Tables II and III).

TABLE II.—*Carbon and Nitrogen Analysis*

Date	Sample Analyzed	Per Cent Total Solids	Per Cent Volatile Solids	Per Cent Carbon	Per Cent Nitrogen
3–13	Undigested sewage sludge	8.30	6.25	3.5	.19
3–27	Undigested sewage sludge	6.30	4.92	2.91	.11
4–17	Undigested sewage sludge	5.19	3.90	2.24	.13
3–13	Paper pulp	31.7	31.55	14.52	.00
4–17	Paper pulp	33.4	33.2	14.10	.00
Ave.	Undigested sewage sludge	6.60	5.02	2.88	.14
Ave.	Paper pulp	32.5	32.38	14.31	.00

		Carbon Per Cent of Total Solids	Nitrogen Per Cent of Total Solids	Carbon Per Cent of Volatile Solids	Nitrogen Per Cent of Volatile Solids
	Undigested sewage sludge	43.64	2.17	57.37	2.85
	Paper pulp	43.96	0.00	44.30	0.00

The feedings of sludge to Unit 9, one of the two units to which no paper pulp had been fed, was stopped on the 40th day but the unit was continued in operation for 17 days longer before the digestion tank was emptied. This was done so that the gas production and digested volatile matter could be determined prior to the completion of the study, from which data some preliminary calculations could be made. All of the other seven units were fed for a period of 64 days, after which they were allowed to operate for 15 days before being emptied. In the process of emptying the tanks all of the sludge was removed and

TABLE III.—*Carbon to Nitrogen Ratio*

Unit No.	Lb. Dried Solids in Undigested Sludge Fed Between 2/11/37 and 4/15/37	Lb. Dried Solids in Pulp Fed Between 2/11/37 and 4/15/37	Lb. Carbon in Dried Sludge	Lb. Carbon in Dried Pulp	Lb. Nitrogen in Dried Sludge	C/N Ratio as Calculated
9	6.278	None	2.74	None	.136	20
10	9.965	None	4.35	None	.216	20
11	8.978	2.313	3.92	1.02	.195	26
12	7.976	3.849	3.48	1.69	.173	30
13	7.034	5.278	3.06	2.32	.152	35.4
14	5.980	5.710	2.61	2.51	.129	39.7
15	4.985	6.035	2.17	2.65	.108	44.6
16	3.987	6.372	1.74	2.80	.086	52.6

Note.—No nitrogen present in pulp.

the tanks were thoroughly flushed out with water. This sludge and flushing water was all weighed and tested for total and volatile solids. Before the paper pulp was weighed for mixing with a weighed amount of undigested sewage sludge, the pulp was pressed by hand in cheesecloth to remove as much as possible of the water that had been added during grinding. The sludge and pulp were thoroughly mixed in a pail and fed to the tanks through the vertical feed pipes. Excess water was added to the mixture when needed to insure flow down the pipes. In Table IV is shown the amounts of undigested sewage sludge and pulp fed daily to the various units during the period of the study. It was necessary to reduce the initial feedings as it was found that the time required could not be given to removing and testing the gas, sludge, and supernatant removed from the tanks under the schedule of the initial feedings.

TABLE IV.—*Daily Feedings Schedule of Units*

(except Sunday)

Unit	Period 2/11–2/12 Undigested Sewage Sludge (Lb. Wet)	Period 2/15–2/20 Undigested Sewage Sludge (Lb. Wet)	Period 2/20–4/15 Undigested Sewage Sludge (Lb. Wet)	Period 2/11–2/12 Pulp (Lb. Wet)	Period 2/15–2/20 Pulp (Lb. Wet)	Period 2/20–4/15 Pulp (Lb. Wet)
9	5.00	5.00	2.50	—	—	—
10	5.00	5.00	2.50	—	—	—
11	4.50	4.50	2.25	.422	.237	.103
12	4.00	4.00	2.00	.722	.372	.174
13	3.50	3.50	1.75	.898	.472	.247
14	3.00	3.00	1.50	1.015	.527	.265
15	2.50	2.50	1.25	1.045	.542	.282
16	2.00	2.00	1.00	1.003	.597	.300

In determining the organic carbon content of the fresh sewage sludge and paper pulp, the method used was that given by F. W. Mohlman and G. P. Edwards in Vol. 3 (1931) of Industrial and Engineering Chemistry, Analytical Edition. The Kjeldahl method as given in Standard Methods was used in determining the organic nitrogen content of the samples of sludge and paper pulp examined. pH determinations were made by the colorimetric method using bromcresol purple or bromthymol blue as indicators. Total and volatile solids determinations were made following Standard Methods procedures using 50 milliliter nickel alloy dishes, a water bath, a gas drying oven, and an electric muffle furnace. Gas analyses were made in a Hempel apparatus and in an Orsatt apparatus.

The entire volume of the digestion tanks could not be utilized due to the overflow of the supernatant liquid from the gauge glasses, caused by the building up of gas pressures in the tanks. In order that some knowledge could be had of the volume of the tanks used to store sludge, measurements were made of each tank on nine different days after gas had been withdrawn and the pressures in the tanks reduced to atmospheric. From these measurements the average volume of the tank capacity used to store sludge and supernatant was calculated and found to be 4.5 cu. ft. Using this figure the average total solids in pounds added each month to the digestion tanks per cu. ft. of tank capacity used was 1.34 pounds. This figure is lower than might be expected in actual operation of a municipal plant but it is not felt to be so low that the same results might not be expected in the operation of a separate sludge digestion tank designed on a basis of 2 to 3 pounds of total solids per cu. ft. of tank capacity per month. There was no great variation of any tank from the average. The highest and lowest averages, were 5.00 and 4.15 cu. ft. of tank capacity used and 1.49 and 1.07 pounds of total solids added per cu. ft. of tank capacity per month.

SLUDGE, PULP AND SUPERNATANT CHARACTERISTICS

Summaries of the characteristics of the fresh sludge and pulp added to the digesters and the supernatant and digested sludge removed from the digesters are given in Tables V, VI, VII, and VIII.

TABLE V.—*Summary of Digested Sludge Characteristics*

Unit	No. of Samples	Per Cent Total Solids			Per Cent Volatile Solids			pH			Per Cent Volatile Solids in Total Solids
		Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	
9	2	11.07	8.17	9.16	6.79	4.10	5.09	7.3	7.1	7.2	54.4
10	4	8.36	6.14	7.42	4.60	3.44	4.10	7.3	7.1	7.1	55.1
11	4	7.46	4.76	6.31	4.26	2.66	3.63	7.2	7.0	7.1	57.5
12	4	9.30	6.91	8.12	4.84	3.63	4.27	7.2	7.0	7.1	52.6
13	4	6.50	5.38	5.82	3.60	3.03	3.19	7.1	6.9	7.0	54.8
14	4	6.95	5.14	6.03	3.74	2.85	3.34	7.2	7.0	7.1	55.5
15	4	7.22	5.62	6.70	3.94	2.97	3.62	7.1	7.0	7.0	51.2
16	4	7.88	4.04	6.05	4.37	2.16	3.32	7.1	6.9	7.0	55.0

Table VI.—*Summary of Supernatant Characteristics*

Unit	No. of Samples	Per Cent Total Solids			Per Cent Volatile Solids			pH			Per Cent Volatile Solids in Total Solids
		Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	
9	2	1.160	.424	.792	.650	.211	.430	7.2	7.1	7.2	54.2
10	3	.251	.227	.239	.132	.110	.119	7.3	7.1	7.1	49.8
11	4	.967	.216	.424	.117	.089	.104	7.2	7.0	7.1	24.5
12	4	.351	.263	.281	.177	.003	.120	7.2	7.0	7.1	42.8
13	4	.381	.200	.284	.173	.094	.139	7.2	7.0	7.1	49.0
14	4	.487	.318	.380	.259	.163	.200	7.1	7.0	7.0	52.6
15	4	.263	.231	.247	.137	.118	.127	7.3	7.0	7.1	51.4
16	4	.647	.222	.354	.361	.122	.195	7.1	7.0	7.0	55.0

Table VII.—*Summary of Fresh Sludge and Pulp Characteristics*

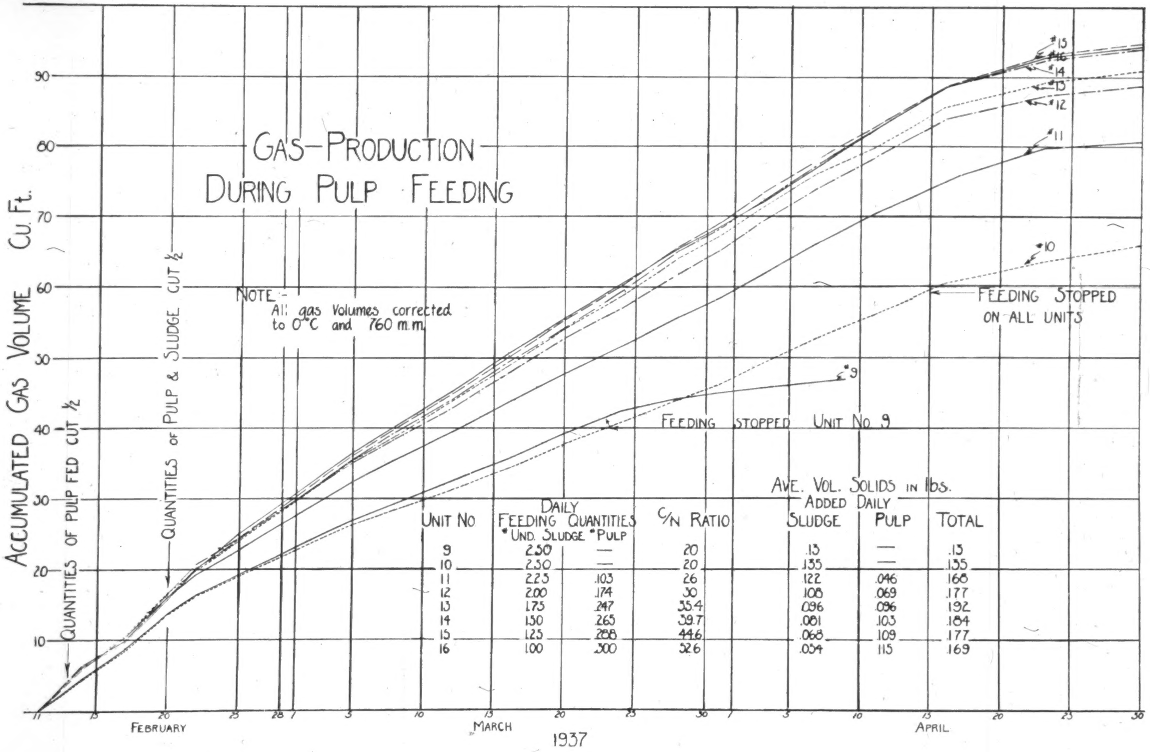
	Per Cent Total Solids			Per Cent Volatile Solids			pH		
	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.
Sludge	12.9	3.5	6.4	11.60	2.58	5.80	5.7	5.2	5.4
Pulp	59.2	27.3	33.15	59.0	27.2	32.99	—	—	—

Table VIII.—*Ratio of Volatile Solids in Pulp to the Volatile in Undigested Sludge Added Daily to Each Digester*

Unit	Ave. Volatile Solids in Undigested Sludge Lb. Added Daily	Ave. Volatile Solids in Pulp Lb. Added Daily	Ave. Volatile Solids Lb. Added Daily	Ratio of Volatile Solids in Pulp to Volatile Solids in Sludge Added Daily
9	0.13	0.000	.13	—
10	0.135	0.000	.135	—
11	0.122	0.046	.168	.38
12	0.108	0.069	.177	.64
13	0.096	0.096	.192	1.00
14	0.081	0.103	.184	1.27
15	0.068	0.109	.177	1.60
16	0.054	0.115	.169	2.13

There was no appreciable difference in the percentage of volatile matter in the total solids withdrawn from any of the digesters. The volatile in all cases was slightly more than 50 per cent of the total solids removed. The hydrogen-ion concentration of the sludge and supernatant gave no indication that the addition of paper pulp to the digesters affected the acidity of the sludge, as the pH of the digested sludge remained fairly constant for all digesters during the period of the investigation.

There was little change in the hydrogen-ion concentration of the fresh sludge added to the digesters, but there was considerable variation



UNIT No	DAILY FEEDING QUANTITIES *UND. SLUDGE	*PULP	C/N RATIO	AVE. VOL. SOLIDS IN lbs. ADDED DAILY SLUDGE	PULP	TOTAL
9	2.50	—	20	.13	—	.13
10	2.50	—	20	.135	—	.135
11	2.25	.103	26	.122	.046	.168
12	2.00	.174	30	.108	.069	.177
13	1.75	.247	35.4	.096	.096	.192
14	1.50	.265	39.7	.081	.103	.184
15	1.25	.288	44.6	.068	.109	.177
16	1.00	.300	52.6	.054	.115	.169

Fig. 5.

in the total and volatile solids. The pulp added to the digesters was mainly of a volatile nature and volatile solids averaged 99.52 per cent of the dried total solids in the pulp.

Gas Production and Analysis

In Fig. 5 is shown the cumulative gas volume produced during the period of the investigation after pulp had been added to the tanks.

Raising or lowering the carbon to nitrogen ratio within the limits used during the study (20 to 52.6) did not seem to have any effect upon the gas production. It appeared that the main factor in increasing gas production was the paper pulp. Those digesters to which the greatest amounts of pulp and the least amounts of undigested sewage solids were added, even though the volatile solids added daily were approximately the same, produced the greatest quantities of gas.

Analyses of gas produced by the digesters indicated a slight increase in carbon dioxide content, an apparent decrease in hydrogen and nitrogen content, and little effect upon the methane content of the gas due to the addition of paper pulp to the digesters. A summary of the average results during the period of the study when pulp was added to the digesters is shown in Table IX. The low carbon dioxide content of the gas can be attributed to the absorption of the carbon dioxide by the water over which the gas was collected. This absorption of carbon dioxide would tend to increase the percentage of methane reported due to the lesser solubility of methane as compared with carbon dioxide.

TABLE IX.—*Average Gas Analyses During Period of Study When Pulp Was Fed to Digesters*

Unit	Ratio of Volatile in Pulp to Volatile in Undigested Sludge	Carbon to Nitrogen Ratio	No. of Samples	Per Cent				
				CO_2	CH_4	H_2	O_2	CO
9*	Control	20	5	23.1	59.9	6.1	0.7	0.3
10*	Control	20	7	24.7	62.0	1.74	0.7	0.3
11	.38	26	7	28.6	69.7	0.4	1.0	0.3
12	.64	30	7	30.9	66.0	0.0	1.1	0.2
13	1.00	35.4	7	31.4	67.1	0.0	0.9	0.3
14	1.27	39.7	7	31.7	65.6	0.0	0.95	0.25
15	1.60	44.6	7	32.8	65.4	0.0	0.95	0.15
16	2.13	52.6	7	33.1	58.5	0.0	1.30	0.15

* No pulp added to digesters 9 and 10.

The graphs shown in Figs. 6 and 7 show the cubic feet of gas produced per pound of volatile solids added to the tanks during the period of the study when the paper pulp was under digestion, for various carbon to nitrogen ratios, and for various ratios of average volatile solids in the pulp to the average volatile solids in the undigested sewage sludge added to the tanks.

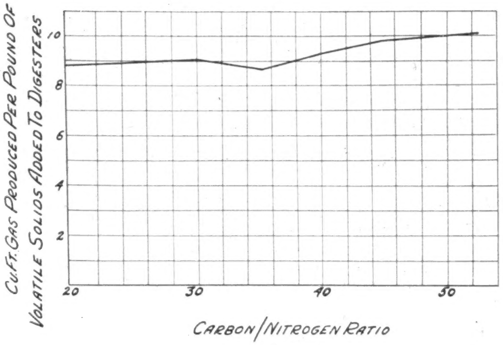


Fig. 6.

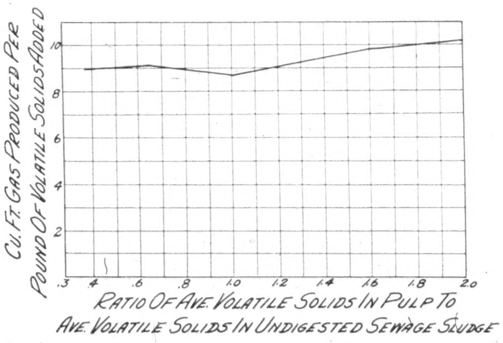


Fig. 7.

Conclusions

This study was undertaken to determine the effect upon digestion of adding mixtures of paper pulp and undigested sewage sludge to well seeded sludge in heated separate sludge digestion tanks. The operation of each digester was carefully checked as to quantities added, quantities removed, characteristics of the solids added and removed, and quantity and quality of the gas produced. Two analyses of the paper pulp and three analyses of the fresh sewage sludge were made to determine the amounts of carbon and nitrogen so that the carbon to nitrogen ratios could be calculated for the mixtures of pulp and fresh sewage sludge added daily to the tanks.

The greatest care was exercised in conducting the study. Although the average amount of total solids added per month per cubic foot of tank capacity to the digesters used in the study (1.34 pounds per month per cubic foot capacity) is lower than that ordinarily experienced in practice, it is felt that the results are indicative of the results which might be expected if mixtures of paper pulp and domestic sewage sludge were added to well seeded separate sludge digestion tanks of a municipal sewage treatment plant.

The conclusions drawn from this study are:

1. Mixtures of paper pulp and fresh sewage sludge when added to well seeded sludge in heated separate sludge digestion tanks digested satisfactorily with a ratio of volatile pulp solids to the volatile solids in the undigested sewage sludge as high as 2.13.
2. No noticeable deleterious effects upon digestion were noted when the ratio of carbon to nitrogen of the sludge added to the tank daily ranged from 20 to 52.6.
3. The volatile solids in paper pulp digested more rapidly or produced more gas than the volatile solids in the undigested domestic sewage sludge.
4. Mixtures of paper pulp and fresh domestic sewage sludge, in which the ratio of volatile solids in the pulp to the volatile solids in the fresh sludge ranged from .38 to 2.13, digested in well seeded sludge digestion tanks without affecting the pH of the sludge during digestion.
5. The addition of paper pulp to fresh domestic sewage sludge increased the carbon dioxide content of the gas produced by digestion.

ACKNOWLEDGMENT

Acknowledgment is made to Charles L. Walker and William E. Stanley, Professors of Sanitary Engineering, Cornell University, for their valuable suggestions and assistance and to Mr. R. A. Rasmussen of the Agricultural College of Cornell University for his time and care in conducting certain of the chemical analysis.

Operators' Reports and Suggestions

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GOOD HOUSEKEEPING *

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As commonly understood, the term "Good Housekeeping" applies to the art of properly administering and managing the affairs of a household. The fundamental principles of good housekeeping include a number of individual activities which might be classified under the general headings of Administration, Operation, Maintenance, Improvement, Extension and Enlargement, and Physical Appearance. In their ordinary application, these terms apply to the duties of a housekeeper.

The same principles that are applicable in the keeping of an ordinary household are also applicable to good housekeeping as related to sewage treatment works.

Administration

The first item for consideration is administration, which includes finance, management and personnel.

Financial responsibility for sewage treatment works is generally vested in the authorities that are responsible for municipal finances. These bodies are the officials of our cities, boroughs and townships.

In considering financing of sewage treatment plants in terms of good housekeeping, it is not necessary in this discussion to review the details essential to the financing of the initial cost of such works. However, when new sewage treatment works are under consideration, it is important to consider the matter of finances from the standpoint of future operation, maintenance, and depreciation cost.

In planning for new sewage treatment works, municipal authorities and their consulting engineers should give particular attention to determining the budgetary item of cost necessary to provide for good housekeeping of the sewage plant after construction is completed, in the same manner that the good housekeeper provides a budget for the operation of the household.

Too frequently in the past the authorities responsible for the construction and operation of sewage treatment works, and the consulting engineers acting in an advisory capacity to these officials, have either failed to take into consideration, or have minimized the item of annual expense for plant housekeeping. This item should be considered as much a part of the financing of sewage treatment plants as the initial cost of construction. The method of raising the necessary funds to operate and maintain the plant efficiently should be given the same consideration as the method of providing funds for debt retirement and interest and should be incorporated as part of a complete financial plan for the successful and continuous performance of this particular municipal activity.

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Annual operating expenses can be raised by one of two methods: either by increasing the tax millage a sufficient amount to provide a proper income to cover the budgetary expense of operation, as is done in the case of debt retirement and interest; or by the newer method of raising funds for debt retirement, interest, operation, depreciation and maintenance, through the adoption of a sewer rental program (Pennsylvania Sewer Rental Act No. 402, approved July 18, 1935, P. L. 1286).

The securing of the necessary funds for efficient plant housekeeping from the general funds raised by general taxation has not always been attained in the past. There are so many needs, particularly in municipalities, for monies raised by general taxation, that in some cases funds provided for sewage treatment plant operation by this method are reduced below any limit which might conceivably be adequate, or perhaps are forgotten entirely.

The creation of a special fund, such as provided for through sewer rental, gives a positive means for securing necessary money for good housekeeping at sewage treatment works and should be preferable to the taxpayers of our communities, who, by this method, realize that they are securing an essential service in the collection and disposal of sewage for which they are making a direct payment.

Under Administration also comes the matters of plant management and operating personnel. In municipalities this duty generally falls on the department having jurisdiction over public works and is vested in the councilman having charge of that department. This official, together with the municipal engineer or manager, assumes the duties and responsibilities of management of the treatment works.

The managing officials will generally have control over operating expenditures and it is their duty to see that (1) an adequate appropriation is made for such purposes; (2) funds thus provided are judiciously expended in accordance with actual need therefor; (3) a proper balance is maintained between income and expenditures; and (4) a satisfactory accounting record is kept of all income and expenditures.

Ordinarily the selection of operating personnel is one of the responsibilities of the management. The good housekeeper will select necessary help on the basis of the particular qualifications and experience of the applicants to perform the required services. The same method of selection should also apply to personnel for operation of sewage treatment plants.

In general, the larger sewage treatment plants and those involving complex methods of treatment will require the immediate and full-time supervision of trained and experienced personnel with a technical knowledge of the art of treatment. At smaller plants it may not be essential to have such technically trained personnel, but in all such cases, the operating personnel should be under the supervision of some competent person or agency.

There have been very many instances where untrained and inexperienced operators have diligently applied themselves to the work and, under proper supervision, have become efficient plant operators. There have been, and still are, cases where some street department employee or policeman of a municipality is responsible for the plant operation as a part-time duty, and where plant operation becomes a matter of secondary or minor importance. Such cases as the latter certainly cannot be classified as good housekeeping.

For the benefit of both management and operating personnel, the consultant who designed the plant should be retained in a supervisory capacity for a sufficient period of time to acquaint them with the operation and functions of the plant and to plan necessary adjustments.

In relation to personnel, this Association might well give further consideration to the matter of the licensing of sewage treatment plant operators, not solely for the purpose of individual advancement of such operators, or for securing continuity of employment, but for the main purpose of better housekeeping at the sewage plants of the municipalities.

Operation and Maintenance

The next item for consideration in good housekeeping would logically include operation and maintenance. No household can be considered as being well kept unless it is operated and maintained for the specific purpose of caring for the health, comfort, and happiness of its occupants.

Sewage treatment plants are also operated and maintained for very specific purposes, the foremost of which are: (*a*) the elimination or effective control of deleterious pollution of surface sources of public and industrial water supplies; (*b*) the elimination of public health nuisance conditions; (*c*) the protection of public bathing places and recreational areas; and (*d*) the preservation of streams for the support of animal, fish and other aquatic life.

Good housekeeping requires the operation and maintenance of sewage treatment works in such a manner as to fulfil these purposes. This can be accomplished by providing for: (1) a sewage effluent of the required degree of treatment for disposal into the receiving body of water; (2) the maintenance and operation of the plant units individually and collectively to perform the functions for which they were intended; (3) the making of sufficient and proper determinations for the control of the purification processes step by step; (4) the utilization of the determinations as yardsticks for measuring unit and plant efficiencies; (5) the maintenance of a proper record of plant operation, including ordinary procedures and unusual conditions; (6) the proper care of plant equipment and structures to avoid unnecessary expense through neglect of such facilities; and (7) the creation of interest and good will on the part of the general public in the treatment plant.

Improvement, Extension and Enlargement

Good housekeeping also embraces improvement, extension, and enlargement. The wise and efficient housekeeper will provide modern improvements from time to time to prevent obsolescence and to secure increased efficiency, and will make enlargements and extensions to take care of the natural growth and increase in size of the family.

Sewage treatment plants likewise must be improved, enlarged, and extended in accordance with needs brought about by changing conditions. Plants should be kept modern by improved methods of operation, by the installation of new and additional equipment, and by the adoption of better processes of treatment to prevent them from becoming obsolete and inefficient within a comparatively few years after they have been constructed.

Changing conditions relative to the use and character of the receiving body of water may necessitate plant extensions. Plants which were constructed a decade or two ago may have provided for a degree of treatment satisfactory for disposal into the receiving body of water at that time. Changes in the use of the stream, of the character of the water into which the effluent is discharged, may necessitate extensions to provide a higher degree of treatment.

Plants constructed within the last several decades to serve forcasted future populations may need enlargement, due to unexpected growth and extension of territory served beyond the tributary area considered at the time of installation.

Still other plants may be overloaded due to both quantity and character of waste waters received. The admission of large volumes of certain types of industrial wastes having a high population equivalent, without preparatory treatment, may require either changes in methods of plant treatment or plant enlargement to care for such wastes.

Some of the older sewage treatment works now in operation have either become obsolete or inefficient due to the failure of the proper authorities to provide for plant improvements and extensions as they are needed. Such plants are producing effluents of inferior quality. In such instances, through failure to provide for necessary improvements and enlargements, the original investment of the taxpayers has not been protected in a proper manner.

Beautification

A very important item in good housekeeping is appearance, both within the house itself and on the exterior. A good housekeeper will keep the house in order, and a good sewage treatment plant operator will keep his plant in good appearance.

Plant beautification has been emphasized within later years as almost a necessity. In years gone by, some sewage treatment works were considered by the layman as more or less of a public nuisance and such plants might have been described as having a certain "nuisance value" in relation to adjacent property.

In modern plants, it is necessary to maintain an attractive appearance to offset this impression of sewage works held by the general public. Plants can be made attractive by expenditure of a small additional sum of money at the time they are constructed. Some of our newer and more attractive plants have removed prejudice from the minds of laymen and, while they may not have enhanced the value of adjacent property, they have not depreciated values to the same extent as would an unattractive plant.

Plant beautification is not new, and the value of such works was appreciated many years ago. Mr. W. L. Stevenson, Director of the Bureau of Sanitary Engineering of the Pennsylvania Department of Health, has referred to his experience with beautification at the Pennypack Creek Sewage Treatment Works, constructed in Philadelphia about 1912. The construction of this 2.0 m.g.d. plant was part of the much larger task of preparing comprehensive sewerage plans for the entire City of Philadelphia, and it was realized at that time that large areas of land would have to be acquired for future works, and that in exercising the right of eminent domain the courts and juries would award damages for the land. Therefore, with purpose aforethought, the plant was provided with grass lawns, flower beds, and shade trees, and the public invited to visit the plant. The superintendent was instructed to keep the entire plant neat and clean, the grass mowed, and the flowers cultivated, and, as a result, on holidays in suitable weather, it was not uncommon to have many people visit the plant and pass favorable comment upon its appearance.

In later work, when the city proceeded with condemnation of land for sewage disposal purposes, it used the attractiveness of the Pennypack Sewage Treatment Plant as an argument in court that it was possible to maintain a sewage treatment works in such a manner that it would not create a nuisance to abutting properties, and it is believed that this forethought on the part of the city saved considerable sums of money in condemnation proceedings which were far in excess of the extra cost of beautification.

Many of our new sewage treatment plants are attractive and many of our older ones could be made attractive with the expenditure of a little money and labor on the plant sites. Grass lawns, shrubbery, and flower beds make for attractiveness, and trees provide shady spots within the area and can be also used for screening the plant against prevailing winds which might carry odors to surrounding property.

It is not intended to substitute plant beautification for plant operation. A plant operator should be primarily an operator and not a gardener. A plant can become so beautified that an operator will pay much attention to doing the work of maintaining the park-like appearance of the plant and may slight operation. Good housekeeping is not being carried forward when a plant operator can always be found mowing lawns, cutting hedge, weeding, pruning bushes, and tending to flower beds at times when screenings should be removed from the screen chamber and properly disposed of, scum should be removed from the Imhoff tank, or clogged nozzles of the trickling filter should be opened, or scum and sludge should be removed from a secondary settling basin. In such cases, the operator has become a gardener and prefers that work to the ordinary work of keeping the plant in good operating condition.

Summary and Conclusion

1. Good housekeeping at sewage treatment plants includes proper administration, operation, maintenance, improvement, extension, enlargement, and appearance.
2. The plant management should provide sufficient annual revenue to insure successful and continuous performance.
3. The adoption of a sewer rental program gives a positive method for securing necessary annual income for good housekeeping.
4. The selection of operating personnel should be made on the basis of qualification and experience to perform required service.
5. Further consideration might be given to the licensing of sewage treatment plant operators for the purpose of securing qualified personnel for plant operation.
6. Sewage treatment plants are operated for the specific purpose of preventing stream pollution, eliminating public nuisances, protecting bathing places and recreational areas, and preserving streams for the support of animal, fish and other aquatic life.
7. Good operation provides for a sewage effluent of the required degree of treatment, efficient maintenance and operation, making of the proper control tests, and the utilization of these tests as yardsticks of efficiency, maintenance of plant records, the proper care of plant equipment and structures, and the creation of public interest in the plant.
8. Plant improvements, extensions, and enlargements should be made to prevent obsolescence, increase efficiency, and meet changing conditions relative to the use and condition of the receiving body of water.
9. Original plant investment should be protected through proper maintenance and operation.
10. Plant beautification offsets the common nuisance impressions of laymen toward sewage works and may result in savings due to avoidance of condemnation proceedings for land taken.

Discussion of "Good Housekeeping"

By George P. Searight

Borough Superintendent, Carlisle, Pa.

Mr. Morgan's paper has covered good housekeeping at sewage treatment plants so well that one is at a disadvantage to open the discussion. I think we will all agree if Mr. Morgan's suggestions were followed they would make plant operation a dream instead of a nightmare.

Administration

The best way to start a discussion is possibly to show some of the results obtained and what we are trying to accomplish at the Carlisle Plant, designed for a population of 17,100. This plant was placed in operation in August, 1935, and consists of hand-cleaned bar screens, a screenings digester, two primary settling basins, two separate sludge digestion tanks, glass covered drying beds, three circular trickling filters, a disinfection house, a resettling basin, and a control house and laboratory.

In Carlisle the annual operation funds are obtained from the general tax levy; the appropriation is made in the annual budget, which is made up by the Borough Manager for the approval of Council. Although I am very much in favor of sewer rentals, I have not advocated them because of the local situation. In Carlisle 75 per cent of the borough is sewered so that practically all the cheaper houses and buildings in the central portion of the town are connected to the sewer, while in the strictly residential sections a large portion is not sewered because of annexations and the development of these areas since 1912, when the majority of the sewers were built. This means that by operating our plant out of the general budget the annual cost is better distributed among the class of properties that can best afford to pay. The annual operation costs for the past three years were as follows:

	1936	1937	1938
Sanitary Sewers			
Repairs to Lateral Sewers	$ 89.92	$ 91.49	$ 186.81
Water and Inspection	864.00	864.00	864.00
Sewage Treatment			
Plant Supervision	550.00	480.00	——
Wages of Laborer	2214.63	2099.88	2097.63
Lawn	250.99	131.53	177.31
Materials and Supplies	696.02	348.70	334.89
Maintenance	303.45	220.51	151.48
Fuel, Light, and Power	167.66	142.59	168.41
Total	$5136.67	$4378.70	$3980.53

In Carlisle the borough manager, who visits the plant at least daily, is strictly responsible for the operation of the plant. The weekly report work and laboratory work is done by an assistant. For several years this work was done by an assistant engineer who worked as an engineer during the construction and installation of the machinery. At present this work is being performed by a man who was timekeeper and office clerk during construction and who spends about one-tenth of his time at this work. The plant is in reality operated by two men working 44 hours a week, with their time slightly staggered so that an operator is at the plant from 7:00 A.M. till 4:00 P.M., five days a week, five hours on Saturday. One of the operators visits the plant several hours on Sunday. If any additional men are needed for mowing the lawn, repair work, or general maintenance, these men are taken from the street or water works forces.

The plant was built as a P.W.A. Project with force account labor with the writer as construction superintendent or engineer and with the Borough's general foreman and about ten of the Borough's regular forces working on the construction of the plant. In order that you may know the type of operators we have, we will call them Operator "A" and Operator "B." When the new plant was put in operation it was necessary to have an operator familiar with electricity and machinery. Therefore, Operator "A" was put in charge of the plant, and he can do a certain amount of laboratory work as well as repair and maintain practically all equipment. This man has been with the Borough for ten years, working previous to 1933 mostly in the water maintenance gang. During the construction of the plant he worked as a semi-skilled workman installing machinery, pipe work, and plumbing as well as doing other similar duties. It might be worthwhile stating that we followed Mr. Morgan's paper in that this operator worked evenings and Saturday afternoons taking care of lawns and flower gardens for some of our citizens. Operator "B" was operator of the old septic tank plant and, therefore, has served the Borough 23 years as sewage operator.

For these reasons we believe our operators were well selected. From this setup you can readily see that we certainly *did know our plant* when it was ready to be put in operation.

Our relations with the consulting engineer have also been excellent. When we decided to rebuild the plant in 1933, Prof. E. D. Walker was obtained as consulting engineer for designing the plant, inasmuch as he had been familiar with the old plant for five years. The consulting engineer visited the plant regularly during construction and has not forgotten us as he still occasionally visits the plant and we talk it over at least at each Convention. The consulting engineer also writes us numerous letters, such as his letter of April thanking us for our 1938 report and questioning the cause of seven clogged sewers; the results obtained by using the digestion tanks separately rather than in series; and the expense of $51.52 for cleaning filters.

Operation and Maintenance

The administration and operation of our plant are very closely related. In addition to what has already been said about operation, we believe that good housekeeping is obtained by the operation data recorded by the operators on three mimeographed weekly sheets placed at points about the plant that are centrally located with reference to the data requirements. These are headed: Disinfection House Record, Control House Basement Record, and Control House Main Floor Record. From these records and laboratory results the weekly report for the Pennsylvania Department of Health is compiled.

The Disinfection House Record consists of amount and rate of chlorine used; the time sludge collector runs; pump counter reading; and to what unit sludge is pumped. The Control House Basement Record requires meter readings of gas produced by each digester; gas consumed as fuel and gas wasted; meter readings of hot water circulated to each digester; temperature of the return heating water from each digester as read from an installed, indicating thermometer; pounds of lime used and for what purpose; pump counter reading; and purpose for which pump was used. The data recorded on the Control House Main Floor Record are: weather conditions and temperature; number of times bar screens are cleaned; the amount of screenings removed to the screenings digester; the amount of material removed from the screenings digester; temperature of the return heating water from the screenings digester; number of primary settling basins in use, time sludge collectors are run; trickling filters in use; when machinery was greased, repaired, or inspected; and sludge placed on or removed from the drying beds and data as to the depth, color, and odor. On each of these sheets sufficient space is available for remarks of any other work, breakdowns or unusual occurrences to be reported. These forms are filed at the desk together with the weekly charts from the various recording instruments, which record the quantity of sewage passing through the plant, the temperature of sludge in each digester, and the temperature of the feed and return heating water to each digester.

From the above information the most important operating data are transferred to a loose leaf record book. This record is in a compact and concise form and aids in comparing results and operation from time to time. Laboratory results are also recorded in this book. The other available laboratory results that have not been referred to are those of digested sludge analyses and relative stability of the stream above and below the plant, of the effluent of each trickling filter, and of the final effluent of the plant.

Although we find it difficult to get our citizens to visit the plant, we do have a great number of visitors. The Sanitation Department of the Medical Field Service School uses our plant for class-room and demonstration purposes at least four times a year, which means that hardly a week goes by without a group from the Army Post visiting the plant. Each year several classes from Dickinson College visit the plant, generally the class in bacteriology and the class in municipal government. For the last couple of years we have been able to get several classes from the senior and junior high schools to visit the plant. It is our experience that these inspection trips accomplish much as the operators surely take pride in showing the high school boys and girls that they have as fine a place in which to work as the water plant.

Improvement, Extension, and Enlargement

Since our present plant has been in operation only four years we are not seriously considering any improvements. But we have at least given thought to the capacity of our sanitary sewers and our sewage treatment plant in case air conditioned installations using Borough water would be generally installed and wasted into the sanitary or storm sewers.

However, our plant occupies a very unique position as to plant improvements and extensions. Between the Borough of Carlisle and our plant is the Medical Field Service School of the United States Army and we treat all the Army Post sewage. Because we are adjacent to a military reservation which might, in emergency, within one month expand to such an extent that our present population served would be doubled or tripled, the War Department has studied our ability to increase operation without interrupting normal service. However, it is hoped that in case this emergency does arise these extensions will be the headache of the War Department rather than of the Borough.

Beautification

In this respect the Borough has taken advantage of the Works Progress Administration and the National Youth Administration.

The work of landscaping and starting the lawn was covered by W.P.A. Projects from which we have obtained very good results. We graded the entire plant area of over six acres and sowed three-fourths of it in grass seed. These projects cost the Borough $250.99 in 1936 and $131.53 in 1937, or a total of $382.52. Last August we notified the citizens, through the newspaper, that we would collect any flowers, plants, or shrubs they wanted to give away, as we needed them for planting at the sewage treatment plant. From about 30 citizens we received at least 7,000 iris, 25 rose bushes, 15 lilac bushes, several beds of tulips, 10 dozen zinnia plants, and about 50 other bushes. By this means we not only received flowers that would have been thrown away, but I think we have been able to get more people to visit our plant. The cost of planting these gifts and mowing the lawn, in addition to the work done by the two operators, was $177.31 in 1938. Then as N. Y. A. Projects, the borough planted this spring 16,000 pine seedlings upon borough property at a cost of $179.35, 4,000 of these having been seedlings planted at the sewer plant. The planting and work done to beautify the plant have not been completed long enough to show the best results but we are confident that with the interest shown we will be able to obtain more flowers and shrubs so that in several years we will have a very respectable looking plant. At present we have the N. Y. A. boys planting and cultivating flowers and trees around the plant.

Conclusion

In order to get good housekeeping the administrator must have the confidence and goodwill of the operators, for a good operator can tell more than can be found by inspection. The operator can not only tell you when someone dumps oil in the sewer or when you need to remove a clog of roots, etc., but he can also tell you when too many rain spouts and cellar drains are connected to the sanitary sewer system. Finally, the best way to obtain good housekeeping at your sewage treatment plant is by inspections and then some more inspections. Well, we get the inspections from the Surgeon General of the United States Army, down to the rear rank pill-roller. Some years ago the Commandant of the Army Post, who was a General with only six months to serve before retirement, spent an entire afternoon sitting under the shade tree near the sludge bed in order to find out whether the flies came from our sewage treatment plant or from the Army Post incinerator or piggery.

Honestly, we believe our plant is a fine example of good housekeeping, but a gang of ten men with seven fire plug streams would start swabbing decks if Ted Moses ever left Harrisburg with the Sanitary Water Board to visit our plant—but there wouldn't be a man in sight, except the operators, when the visitors arrived at the plant.

LABORATORY CONTROL OF SEWAGE TREATMENT *

By M. W. Tatlock

Superintendent, Sewage Treatment Plant, Dayton, Ohio

"Nature Unincorporated" gave us a world with pure water in abundance but "Man and Company," through the intricate processes of domestic and industrial life, has given us sewage or "water-plus" and the engineer's problem in developing the processes of sewage treatment, or the subtraction of the "plus" from the water, may be summarized as follows; primary treatment, the removal by physical means, of the coarse floating and suspended matter through the aid of skimming devices, screens and grit chambers and of the finer suspended matter by sedimentation and coagulation; chemical treatment, which usually incorporates the application of pH adjusting and coagulating chemicals along with the primary treatment devices and produces a somewhat higher quality effluent; secondary treatment, the removal of the very fine suspended, colloidal, and soluble organic matter by chemical oxidation through the aid of biological processes; polishing of effluents, which includes some oxidation of organic matter by chlorine or the removal of such matter by filtration processes; and, finally, the reduction or digestion of the removed solids (sludge) by anaerobic bacteria or, more recently, the reduction of raw and digested sludges by vacuum filtration and incineration. The collection and use of the gas produced by digestion of these sludges has introduced mechanical problems incident to its use in power units for reducing operating costs. With all these considerations of sewage and its contaminating materials, the conditions of the stream both before and after receiving the treated sewage must not be overlooked. The study and control of these processes by the skilled laboratory technician is the problem of Laboratory Control of Sewage Treatment.

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* Presented at the Thirteenth Annual Conference of the Pennsylvania Sewage Works Association, State College, June 27, 1939.

It has not been many years since sewage treatment plants were designed and built with no consideration given to a control laboratory as an essential part of the plant structure. The mechanization of treatment has had much to do with obtaining better supervision and operation for it is only natural that an operator on the job from 8 to 24 hours a day should make a few tests to aid in his operation and knowledge of the plant. The state departments of health have urged better supervision and the designing engineers have urged more and better laboratory facilities until a point has now been reached where the works laboratory is an integral part of the original plant design as a part of the original cost.

In the further consideration of this subject one might assume the presence of a skilled laboratory technician in a modern laboratory, but some thought may well be given to the qualifications of a good laboratory technician and what should be incorporated in a modern laboratory. It is the belief of the writer that there are two distinct types of laboratory technicians and that each has a very essential place in a modern, well-equipped, sewage plant laboratory. The basic training of each type should include studies in mathematics, physics, the biologic, zoologic and chemical sciences, and each must possess energy and enthusiasm for his work; the distinction between the two types would be based on their natural inclinations to the problems at hand. The one should be able to perform all the routine tests and to interpret them into terms of plant operation, being able to advise on plant operating procedures from his laboratory observations and determinations. The other, the research man, should possess broad powers of observation and be able to interpret results without preconceived ideas. He should possess a creative imagination and a broad knowledge in the different allied fields of activity.

The laboratory room or rooms should be adequate but not oversized, with ample storage facilities for distilled water, supplies and equipment which are not subject to daily use, with work tables, sinks and equipment racks, cupboards or drawers conveniently arranged. There is no definite rule for convenience but generally speaking it would seem advisable to provide separate rooms for biologic and chemical work and a general arrangement or set up to avoid all unnecessary steps and the carrying of equipment or samples to any great extent. The following facilities should be provided for complete laboratory control and research work: refrigeration and incubator space with thermostatically controlled temperatures of 3°, 20° and 37° C.; fumehood with forced draft fan; an automatic still for distilled water; sterilizing equipment for both wet and dry sterilization; acid digestion equipment and ammonia still for nitrogen determinations; grease extraction apparatus; water baths; drying ovens; muffle furnace with pyrometric control; desiccators and balances; vacuum filtration equipment; calorimetric equipment for solids, liquids and gases; gas analysis apparatus; microscope and Petri plate counter; equipment for the physical analysis of oils and lubricants; equipment for measuring the oxygen consumption by sewage, mixed liquor or sludges, such as the "Odeeometer" or the activated sludge oxygen consuming device developed by Bender and Bloodgood at Indianapolis; a good centrifuge; and, of course, such utility provisions as hot and cold water, gas connections, 110 and 220 volt electric connections, and methods for disposing of waste water in sufficient number and conveniently placed. In this enumeration quite likely something essential has been omitted; it may also contain provisions for work which will never be necessary at many plants.

No mention has been made of the tests which should be made for complete laboratory control. It is not the intent of this paper to discuss the subject from the standpoint of the method of making the tests, but rather to indicate some points of the tests as applied to the most intelligent and efficient operation of a sewage treatment plant.

Since sewage is "water plus" the entire consideration of laboratory control should be based on the quality of the water which becomes sewage by the additions of the by-products of our domestic and industrial life. A complete chemical analysis of the water supply should be available. The total solids in the water and the hardness of the water will affect the quantity of ether soluble materials in the sewage through its action on the soaps; a high sulphate content will affect the production of H_2S; the chlorides content should be known so that the chlorides test on the sewage may be interpreted; and the alkalinity of the water may be reflected in the pH of the raw sewage and affect the treatment processes, whether they be plain sedimentation, biologic, or chemical.

The treated water, except for sea coast or lake towns, is usually returned to a flowing stream. It is, therefore, essential that complete data be available as to the stream flow, its temperature, its dissolved oxygen content, its biochemical oxygen demand, its chloride and alkalinity content, and turbidity, before it is received at the treated sewage and at a number of points up to about 5–10 miles below the plant, the distance to be determined by the rapidity of stream flow. A careful analysis of these data will clearly indicate whether the plant is performing the work for which it was designed and built.

The sewage delivered to the plant, being a composite of the city water supply and the by-products of domestic and industrial wastes, reflects the type of life and industry of the locality. A survey of the industries will indicate something of the problems to be encountered in the treatment processes but the laboratory tests are an infallible guide and guard to the plant operator. In addition to this information, he should keep a record of rainfall and daily temperatures, the temperature of the sewage, its dissolved oxygen, its bio-chemical oxygen demand, the total solids, the percentage of fixed and volatile matter, the chlorides, the alkalinity, the ether soluble content, the nitrogen content as free ammonia, nitrites, nitrates and total organic nitrogen. These tests should also be made on the plant effluent in order to measure the plant efficiency and if the plant is of the chemical or biologic type, then Petri plate counts for bacteria at both 20° and 37° C. and *B.-coli* determinations are advisable on both the untreated and treated sewage. Mechanical tests for odor, color and turbidity will indicate the presence of trade wastes or septic sewage, and give some indication as to the removal of the sewage colloids. The oxygen consumed test (permanganate) is of great value in estimating the concentration of some of the industrial wastes in raw sewages.

It was suggested in the reference to the muffle furnace that it should be thermostatically controlled. This control is essential in order that all materials may be ashed at exactly the same temperature (103° C. is standard procedure) so that the final CO_2 content will be constant. Another point which must not be overlooked in the B.O.D. test is that the diluting water must not be contaminated in any amount with copper as such contamination will show a decidedly reduced B.O.D. It is generally understood that the B.O.D. test measures the extent of carbon oxidation and the determinations of nitrogen, ammonia, nitrite and nitrate show the removal and oxidation of the nitrogenous materials in the sewage.

The "plus" removed from the sewage, the sludge, is usually first treated by a digestion process before its ultimate disposal, but some late developments suggest the disposal of the raw sludge by filtration and incineration. If digestion is employed, the essential tests include determinations of pH and volatile acids, to measure the sludge acidity and find whether the digestor is overloaded with organic matter; the determination of total solids, volatile solids, and ash, to measure the percentage digestion; and complete gas analyses, which will indicate the completeness of the digestion process and the heating value of the gas. The solids and ash tests should be made on both the drawn sludge and the supernatant liquor. If the solids are to be processed and sold for fertilizer, then a complete chemical analysis should be carried out at least each week. The principal usually recognized fertilizing elements are nitrogen, phosphoric acid and potash, but recent experiments in promotion of plant growth indicate that the great variety of so-called rarer elements found in sludge, exert a great influence on the growth of many plants. If one wishes to go into the fertilizing values of sludge the field of work seems to be almost unlimited since it involves not only a study of the chemical constituents of the sludge but of the soil upon which it may be applied.

The production of gas in the process of digestion presents another wide field for treatment plant laboratory studies. The presence of hydrogen sulfide in the gas gives us the problem of odors and their correction. The familiar "rotten-egg" odor is usually detected some place about the plant. While hydrogen sulfide itself is not seriously corrosive, its products of oxidation, water and sulfur dioxide (SO_2), unite to form the highly corrosive sulfurous acid (H_2SO_3). It is essential that the quantity of H_2S present in the gas be known, in order to calculate the size of scrubbers and the quantity of oxidizing materials to be used. Iron oxide or "iron sponge" is usually used for this purpose. If the use of gas for power production is contemplated then the heat analysis of the gas becomes of the greatest importance, since a study of the heating value of the gas is the base upon which engine size and design is based. This factor also enters into the amount of heat wasted and the heat which may be recoverable for general heating purposes. There is an optimum operating temperature for each engine and the amount of available heat will again determine the provisions which must be made for the circulation and cooling of the jacket water. If this water is passed through the digester heating coils, these coils must extract a fixed amount of heat from the jacket water both winter and summer, or provisions must be made for a separate water cooler. And again, if the sludge is to be burned after digestion, the consideration of the B.T.U. value of the gas as a fuel for incinerator and of the B.T.U. value of the sludge itself are the facts which determine the basic design features of any successful operating unit. Other factors entering into the digestion of the solids, the production of gas, and the quality of the sludge, whether it be for use as fertilizer or for fuel, are the per cent solids, the per cent ash, and the amount of ether soluble materials.

The operator who is applying chlorination must fit its use to many conditions for economic results. Not until the ortho-tolidin test was developed into a practical method for measuring residual chlorine, did chlorination practice become acceptable and subject to dependable and economic control. Whether the chlorine be applied for odor control or sterilization, for B.O.D. reduction, or grease separation, to increase the efficiency of overloaded treatment plants, or to reduce the ponding and increase the efficiency of trickling filters, to conserve digestion capacity, or relieve bulking of activated sludge, its economic use will be determined by laboratory measurement of the demand of the original sewage and the residual chlorine after treatment, except where it is used for sterilization or sludge bulking, when the bacterial and *B. coli* counts will be the essential measures of its successful use.

There are many miscellaneous tests and equipment or supplies which might be included in these considerations of the laboratory control of sewage treatment works but there may be some question as to their economic value; the cost of making the tests might overbalance the gains from having made them. Such tests might include the analysis of lubricating oils and liquid or solid fuels, of paints or other protective coatings, of bituminous materials for driveways about the plant, of insecticides for plants, flies, or cockroaches.

The plant laboratory is the proving ground of the designing engineers' product and the plant superintendent should be supplied by the engineer with all the basic design data and should be advised to the last detail as to what the plant is expected to do. Then the laboratory should be used to study each process in detail so that the results may become, for both the engineer and the superintendent, not only a "record of accomplishment" but a basis for improvements in operation and future design. Then again the work in the laboratory should extend beyond the improvement of the present plant and accepted processes into some studies of new methods of analyses, and of new processes, for there are many problems yet unsolved and who is closer to them than the plant operator and his chief chemist?

OPERATORS' SUGGESTIONS TO DESIGNING ENGINEERS

From "The Digester," August, 1939, Illinois State Department of Health,
Division of Sanitary Engineering

C. W. Klassen, *Chief Engineer*
W. H. Wisely, *Editor*

General.—1. Location of plant unnecessarily close to residential property puts the operator under a severe permanent handicap. More attention to choice of site is urged.

2. Diversion chambers on large combined sewers should not permit entrance of playing children. Tragic accident nearly resulted from this at one place.

3. Small, gas-engine driven portable pump desirable for miscellaneous service.

4. Venturi meters located in separate, *drained* vaults outside of building best. Should not be located in wet well.

5. Steel weir plates, bolts, valve stems, etc., just will not last around a sewage treatment plant.

6. A plentiful supply of good water under pressure is an essential to good sewage plant operation. Although this may occasionally be costly, it really is a necessity.

Screens and Shredders.—1. Bar spacing of manually cleaned screens to give 1½ inch clear opening considered best. Two inch openings too large and one inch openings too small.

2. Although opinions varied as to whether it is best to locate comminutors before or after grit removal, most operators favored comminution *after* grit removal.

3. Comminutor motors should be located well above high water elevations.

Grit Chambers.—1. Grit removal facilitates desirable at *all* plants, regardless of type of sewer system.

2. Should be located ahead of pumps if at all possible.

3. Deep grit chambers intended to be manually cleaned are very unsatisfactory. Mechanical grit removal equipment desirable in all chambers more than 6 feet deep.

4. Sufficient usable space for removing and handling grit should be provided for in locating units.

Sewage Pumping.—1. When long, narrow wet well is employed, the dry weather flow pump should be located at the end farthest from the inlet so that the bottom will scour and solids deposition will be minimized. Bottom should be sloped to suction pipes.

2. Manhole or other means of entry to wet well should be located outside of building. If opening *must* be indoors, tightly bolted and gasketed cover should be used.

3. Electrical control panels and switch boxes should not be located in deep pits where dampness exists.

4. Piston type check valves on sewage (or sludge) pump discharge lines definitely unsatisfactory. Flap or ball checks should always be specified.

5. Emergency overflow is highly desirable to prevent flooding of dry well and motors.

Primary Sedimentation.—1. Special care should be taken to obtain smooth concrete on inside of Imhoff tank settling channels and in sludge hoppers of plain sedimentation tanks. Rough walls require frequent cleaning.

2. Channels carrying raw sewage (particularly at settling tank inlets) should be designed to minimize deposition of soils therein.

3. Mechanical skimming devices *always* needed at separate sedimentation tanks.

4. An overflow weir (adjustable) should *always* be provided at the effluent channel of primary tanks to insure against flooding during extreme flows.

Sludge Pumps and Piping.—1. Sludge pumps with suction lift have proven troublesome on primary and secondary tank sludge lines. Positive suction head on *all* sludge pumps is recommended.

2. Provision should be made for draining all infrequently used sludge piping.

3. Sludge sampling cocks should be non-splashing, sampling point should be close to sludge pipe to minimize waste and waste drain should be provided.

4. Cross or tee at bends in sludge (and gas) piping provides convenient cleanout in case of clogging.

Sludge Digestion Tanks.—1. Should never be located deep in ground where ground water level is high because of difficulty in heating.

2. Entrance to control chamber by side-entrance door is safer and generally more satisfactory than by manhole in roof.

3. Deep sink should be provided to receive waste from supernatant sampling pipes. This piping should never be less than 1½ inches in diameter.

4. When heating coil header is used, the header should be located in the control chamber—not inside digester.

5. Raw sludge feed pipes should discharge as far as possible from supernatant outlets (according to O. P. Rator). If the discharge point is 15 to 20 feet from the supernatant outlets it should be all right, however.

6. Provision should be made for prevention of surface water collection in floating covers or else for drainage of such.

7. Convenient means for making digester temperature observations is highly desirable.

8. Leaded joints of cast-iron pipe heating coils eventually open up because of expansion and contraction. No difficulties reported with wrought iron pipe having threaded joints.

Gas Collection Facilities.—1. Arrangement and location of piping and appurtenances should be such that inspection and maintenance can be afforded without engaging a contortionist. (We heard of a gas meter installed backwards, which had to be read with a mirror.)

2. Special precaution should be taken to assure plenty of slope and a permanent foundation for outside, underground gas lines, to prevent settling.

3. Gas meter should be protected by adequate drip traps and connecting piping should include unions to facilitate removal of meter. By-pass around meter is essential.

4. Rotary type gas meters best for large, uniform gas flows. Diaphragm type meters best for small, variable flows.

5. Waste gas burner should be located at least 50 feet from any other structure.

Sludge Drying Beds.—1. Provision should be made for protection against surface water wash on to sludge beds by affording good drainage.

2. Truck tracks in sludge beds should be sufficiently wide to permit entrance of double-wheel trucks.

3. Entry to truck track should be at least 10 feet wide.

Trickling Filters.—1. In some fashion, nearly all trickling filter plant operators have provided some sort of removable 1/4 to 1/2 inch wire mesh screen to remove nozzle and orifice clogging objects from the settled sewage. Could not this be provided for in design?

2. Operators opine that *all* trickling filters should be designed so they can be flooded for fly control.

3. Least difficulty with "pooling" is reported where filter stone 1½ to 2½ inches in size is used.

Activated Sludge.—1. Return activated sludge wells should not be so large that sludge can become stale and septic therein.

2. Ports, channels and piping should be designed to minimize variation in aeration tank water surface elevation. Variations of one inch between low and high flows not harmful.

3. Variable discharge return sludge pumps are regarded highly for their flexibility.

Service Building and Laboratory.—1. Laboratory water faucets should be at least 15 inches above bottom of sink to permit washing of glassware. Regular laboratory sink (with gooseneck faucets) or deep slop sink is satisfactory.

2. Even in small sewage treatment plants, a privy at the rear of the grounds appears slightly inconsistent. After all, a water-flush toilet doesn't cost much.

3. Several operators of large plants indicated a desire for closet space for storage of records, etc.

4. If screens or comminutors are housed in service building, they should be partitioned off, the screen room provided with an outside door and given good ventilation.

VOLATILE MATTER FROM 'ROUND ABOUT

News from Illinois Operators

Belvidere.—Superintendent Miles Lamb really rang the bell with his first annual report, a copy of which reached us recently. The report includes a complete description of the plant, a summary of operation procedures, detailed laboratory data and a complete cost analysis. A graphical demonstration of how power consumption is being constantly reduced by careful operation control is of particular interest.

Lincoln.—A modern version of the story about the little Dutch boy who plugged a leak in the dike with his finger until aid came to save the town from flooding, was enacted here recently. When a leak broke through the sludge bed wall while sludge was being drawn, did Loren Stringer hesitate? No! No! A thousand times No! Into the breach leaped Stringer, plunging into the half-filled bed to block the leak with his shovel. Our hero!

Kankakee.—"Free Sludge Available at Sewage Plant," read a recent, local newspaper caption here. A description of the sludge and directions for its proper application were offered with the invitation to "come and get it." Our guess is that Superintendent Phil Schriner's stock pile is plenty small by this time.

Barrington.—Troubled with a chronically bulked activated sludge, Superintendent Fred Hager decided, upon investigation, that the return sludge was becoming septic in the receiving well. To reduce the retention therein, he placed concrete blocks in the well bottom to form a channel at the pump suctions. Immediate improvement in the condition of the activated sludge proves that Fred figured rightly.

Gillespie.—Operator Wess Sneeringer was recently initiated into the S.O.W.H.E.S.S. (Society of Operators Who Have Experienced Saturation in Sewage). Sneeringer opines that "if anybody doubts that it is a mean trick on the fish to dump raw sewage into a stream, just tell them to fall in an Imhoff tank!" Thanks Wess, we'll take your word for it.

Bloomington-Normal.—Speaking of fish, the effluent here is so good that numerous fish come up into the plant outfall channel. Superintendent Hendryx and Chemist Corrington have managed thus far to leave their fishing tackle at home and to keep their minds on trickling filters, sludge and stuff. They are making no promises, however!

Edwardsville, Highland.—Finding themselves handicapped by lack of sludge drying area during that early Spring critical period, Harry Hanser and Harold Gnaegy, respectively were glad to try alum treatment of the sludge as drawn to speed drying. At Edwardsville, one pound of alum to 85 gallons of sludge caused a 12-in. draw to shrink to a 5-in. depth in 18 hours. The sludge was removed in two weeks. At Highland, similar treatment made it possible for an 8-in. draw to be removed from the beds in just one week!

The alum seems to separate the moisture from the sludge and to cause the solids to float. This allows a large part of the water content to drain through the sand very quickly. The demonstration at the Edwardsville sectional meeting was so effective that Shorty Spiess at Litchfield and Maynard Long at Hillsboro could hardly wait to get home to give the idea a trial!

Hinsdale.—Operators Greek and White have nothing against soft water but they don't have much use for the sludge that reaches their plant from the city water works where the lime-soda softening process is used. The results of a highly practical study of the effect of this sludge on the sewage treatment works were reported at the Arlington Heights sectional meeting by Ed Greek. His conclusions follow:

1. Lime sludge should be released to the sewer at a low rate of discharge.
2. When concentration of lime in sewage was about 350 p.p.m., the efficiency of suspended matter removal in the Imhoff tanks increased from 64 to 82 per cent.
3. Lime sludge increases pH of sewage (which is beneficial as this freshens the sewage and retards odor production).
4. About twice as much digestion volume is required in Imhoff tanks when lime sludge is to be taken as is needed for domestic sewage only.
5. Although lime content allows sludge to be drawn in a less digested condition, the solids concentration may reach 25 per cent, causing difficulty in obtaining flow through piping. Digested sludge containing spent lime is also more difficult to dry, requiring about four weeks as a minimum.

FIRST REPORT OF THE BELVIDERE SEWAGE TREATMENT DEPARTMENT, BELVIDERE, ILL., 1938

By Miles Lamb

Superintendent

Administration

The Belvidere Sewage Treatment Works operates under the Sewage Revenue Bond and Service Charge Law enacted by the 58th General Assembly in 1933, and all monies are derived from this source. The responsibility for the operation and maintenance together with the collection of the revenue for sewer service rests with the Sewage Treatment Department.

Bills are issued quarterly and are payable at the collection office of the Department, which is in the City Hall. The amount of the bill is based on the water consumption. The minimum charge with the 10 per cent discount allowed for payment before the 20th of the month is 68 cents per month. For the purpose of billing, the city is divided into three sections. These sections are billed in rotation. By this method a steady monthly income is assured. Delinquent bills become a lien on the property. To date about 97 per cent of the billings have been collected. In 1938, the cost of collecting the revenue was about 6 per cent of the total billings.

The regular personnel of the Sewage Treatment Department is as follows:

1—Superintendent, who is also City Engineer
1—Clerk
1—Operator
1—Night Watchman

During the year considerable work was done in the improvement of the plant grounds. For this purpose a laborer was employed. Much assistance in this work was given by the National Youth Administration.

Once each month, and at the close of the fiscal year, the Superintendent reports to the Mayor and Council in writing. These reports contain statements of revenue collected, itemized accounts of money spent, and performance of the Sewage Treatment Works.

Description of Plant

Design Population	10,000 people.
Present Population	8,100 people.
Design Flow	1.18 M.G.D.
Plant Capacity	2.00 M.G.D.
Grit Chambers	Manually cleaned, one f.p.s. velocity at 30 seconds detention period on designed flow.
Bar Screens	Manually cleaned, $\frac{7}{8}$ inch clear openings.

Flow Meter	Parshall Flume, with Builders' Iron Foundry Transmitter and Recorder.
Pumping Station	Two Chicago Pump Co., 900 G.P.M. vertical pumps, with automatic float control.
Primary Tanks	Rectangular, with Link Belt sludge scrapers—one hour detention period on design flow.
Primary Sludge Pumps	Chicago Pump Co., 75 G.P.M. Scrupeller with variable drive.
Digester	Single-stage heated tank equipped with Pacific Flush Tank floating cover. Capacity, 3.8 cu. ft. per capita with present population.
Aerators	Nine Chicago Pump Co., mechanical aerators equipped with 3 h.p. motors and time control. Aerators are operated as three batteries of three units each. Eight hours detention period on design flow plus 25 per cent return sludge.
Return Sludge Pump	Chicago Pump Co., 250 G.P.M. horizontal pump with variable drive.
Secondary Tank	Rectangular with H-wiers. Link Belt sludge collectors. 2 hrs. detention period on design flow.
Drain Pump	Chicago Pump Co., 500 G.P.M. horizontal pump with variable drive.
Chlorine Contact Chamber	20 minute detention period on design flow.
Chlorinator	Wallace and Tiernan manually controlled.
Sludge Drying Beds	Open type, 1.2 sq. ft. per capita.
Gas Utilization Equipment	Pacific Flush Tank Type B flame trap, pressure relief unit, and waste gas burner. Bryant boiler capacity 396,000 B.T.U. per hour with circulating water pump. No gas meter.

METHOD OF OPERATION

Screens.—The screens are raked five times daily and if necessary, as in case of storms, during the night. The screenings are buried. During 1938, the amount of screenings averaged about one cubic foot per day. Due to the large openings in the screens it is necessary to clean the check valves of the lift station weekly.

Flow Meter.—The flow meter is checked for accuracy once each month.

Primary Tanks.—Both units are operated continuously. The sludge scrapers are run for one hour before the raw sludge is pumped. Scum is removed to the scum trough during the time that these scrapers are running. Very little trouble with floating sludge is experienced.

Digester.—Raw sludge is pumped to the digester at 8 A.M. and again at 4 P.M. Samples of the sludge are taken every five minutes during the pumping period, and composited for laboratory use. Great care is taken to see that the sludge is as concentrated as possible. The total volume of sludge pumped is computed by the rise of the floating cover; each day an amount of supernatant liquor equal to the previous day's pumpage is removed from the digester and placed on the sludge beds. Sludge is removed whenever an analysis of the contents of the tank shows removal to be necessary.

Sludge Beds.—The digested sludge is removed from the drying beds by means of a wheelbarrow, and placed in a stock pile. From the stock pile, it is given away to any one desiring to use it as fertilizer. No trouble has been experienced in disposing of the sludge since it has been stock piled. However, efforts to have those desiring it to remove it directly from the beds did not meet with success.

Gas Utilization Equipment.—All drip traps and seals are inspected every day to insure proper operation. The safety devices on the boiler are checked frequently.

Aerators.—The activated sludge unit receives the entire flow from the primary tank. Careful check is kept on all factors which influence the operation of the activated sludge process, in order to insure the most efficient and economical operation possible. Aerators are cut in and out of service and time clock operation used in order to meet the changing oxygen demand brought about by either changes in the volume or strength of the sewage. This demand can be measured by either the chemical method or an Odeeometer.

From 500 to 700 parts of suspended solids are carried in the mixed liquor and in general, the suspended solids are kept lower in the summer than in the winter months.

CONTROL LABORATORY

The operation of the plant is controlled from the information furnished by the analytical tests obtained in the laboratory. All laboratory work is done by the Superintendent who is a graduate engineer.

The following is a schedule of the laboratory work which was maintained during the year.

Biochemical Oxygen Demand	
Raw, Primary, and Final	Every 3 days.
Suspended Solids	
Raw, Primary, and Final	Every 3 days.
Mixed Liquor	Daily.
Settleable Solids	
Raw, Primary, Final, and Mixed Liquor	Daily.
Sludge Index	Calculated daily.
Hydrogen Ion Concentration	
Raw, Primary, Final, and Digester	Daily.
Total and Volatile Solids	
Raw Sludge	Daily.
Digested Sludge	As drawn.
Supernatant Liquor	Occasionally.
Methylene Blue Stability	
Final	Daily.
Dissolved Oxygen	
Aerators	Twice daily.
Final Effluent	Daily.
Kishwaukee River above and below plant	Daily.
Oxygen Demand of Mixed Liquor	Frequently.

The B.O.D. and suspended solids tests are made from composite samples taken hourly in proportion to the flow from 8 A.M. to 6 P.M.

Since there is no gas meter, gas production is calculated from the daily additions of volatile solids.

On the last day of each month an analysis is made of the contents of the digester. Samples are taken at 3-ft. intervals and from these samples the per cent dry solids and volatile solids, temperatures and pH, at the various levels are determined.

OPERATING DATA

A summary of the work done by the plant in 1938 is shown in Table I.

TABLE I.—*Summary of Work Done By Plant in 1938*

Month	B.O.D.			Suspended Solids			Settleable Solids		
	P.P.M.		Per Cent Red.	P.P.M.		Per Cent Red.	C.c. per L.		Per Cent Red.
	Raw	Final		Raw	Final		Raw	Final	
Jan.	248	5	97.9	227	5	97.8	8.6	0	100
Feb.	152	8	94.9	179	10	94.5	8	0	100
Mar.	223	8	96.4	221	5	97.8	10.6	0	100
April	213	7	96.7	221	3	98.2	9.8	0	100
May	213	6	97.2	185.4	2.3	99.0	9	0	100
June	180	6	96.8	178	3	98.4	7.8	0	100
July	182	5	97.4	158	2	98.8	7	0	100
Aug.	173	4	97.8	170	2	99.0	6	0	100
Sept.	266	8.5	96.8	188	3.5	98.1	6.6	0	100
Oct.	207	7	96.7	235.1	3.7	98.4	7.8	0	100
Nov.	222	6.5	96.8	200	2.6	98.5	6.7	0	100
Dec.	206	8	96.1	187.9	3.7	97.8	8	0	100
Av.	207	6.6	96.7	196	3.8	98.3	7.1	0	100

Average Daily Flow	780,000 Gals.
Maximum Daily Flow	1,530,000 Gals.
Average Flow per Capita per Day	96 Gals.
Average lbs. B.O.D. per Capita per Day	0.166
Average Per Cent Reduction B.O.D.	96.7
Average Per Cent Reduction Sus. Solids	98.3
Total lbs. Dry Solids to Digester	654,438
Average lbs. Dry Solids to Digester Daily	1,830
Average lbs. Dry Solids per Capita per Day	0.224

Primary Tanks.—Table II shows results of operation of the primary tanks. These tanks gave an average reduction of B.O.D. of 38.6 per cent, and 46.6 per cent in suspended solids.

Digester.—The operation of the digester for the year is shown in Table III.

TABLE II.—*Primary Treatment Data, 1938*

Month	Av. Daily Flow M.G.D.	Av. Det. Period Hr.	B.O.D.			Sus. Solids			pH Raw	Temp. Raw
			P.P.M.		Per Cent Red.	P.P.M.		Per Cent Red.		
			Raw	Pri.		Raw	Pri.			
Jan.	0.622	1.92	248	158	36.0	227	126	45.0	7.5	45.0
Feb.	0.844	1.42	152	116	24.0	179	120	33.0	7.5	47.0
Mar.	0.784	1.53	223	127	43.0	221	124	44.0	7.5	48.7
April	0.866	1.35	213	121	43.0	221	104	53.0	7.5	54.6
May	0.834	1.43	213	124	42.0	185.4	111.4	40.0	7.4	60.0
June	0.922	1.30	180	105	42.0	178	104	42.0	7.3	62.0
July	0.914	1.30	182	107	41.0	158	87	45.0	7.3	70.7
Aug.	0.836	1.44	173	113	35.0	170	82	52.0	7.3	72.0
Sept.	0.790	1.51	266	150	44.0	188	100	47.0	7.4	66.5
Oct.	0.540	2.25	207	123	40.5	235	97	58.7	7.5	61.0
Nov.	0.684	1.75	222	148	33.3	200	100	50.0	7.5	57.0
Dec.	0.702	1.71	206	126	38.8	187.9	106.3	43.4	7.5	53.5
Av.	0.780	1.58	207	126	38.6	196	105	46.5	7.4	57.7

TABLE III.—*Digester Data, 1938*

Month	Av. Gals. Added Per Day	Av. Per Cent Dry Solids	Av. lbs. Dry Solids Per Day	Av. Per Cent Vol.	Av. lbs. Vol. Solids Per Day	Av. pH	Av. Temp.	Estim. Gas Prod., 1000 C.F. Per Mo.
Jan.	5720	4.0	1910	78.5	1500	7.1	73	227
Feb.	3390	6.2	1715	76.6	1350	7.1	73	326
Mar.	4030	4.5	1501	70	1041	7.1	75	290
April	4430	4.1	1530	72.4	1101	7.2	81	297
May	4936	4.5	1870	65	1220	7.4	89	342
June	5980	4.9	2460	61.1	1540	7.3	93	414
July	5690	4.8	2230	57.5	1290	7.3	94	351
Aug.	6310	4.1	2120	58	1250	7.2	95	348
Sept.	5780	4.2	2030	60	1220	7.2	92	331
Oct.	6100	3.0	1520	69	1050	7.2	92	291
Nov.	5780	3.2	1550	76	1180	7.2	86	301
Dec.	5420	3.4	1520	75.7	1130	7.2	77	315
Total								3938
Av.	5390	4.2	1830	68.2	1240	7.2	85	328

There were no indications of foaming during the entire year, and with the exception of a few days after the flood, more than sufficient gas was produced for heating purposes. For 72 hours after this flood it was not possible either to heat the digester or to add solids. As a result of these unfortunate circumstances gas production fell to about one-third of normal. This made it necessary to use a kerosene torch to provide sufficient heat to operate the boiler. It was necessary to use this torch for about a week.

Secondary Treatment.—A summary of the operation of the secondary treatment units is given in Table IV. The efficiency of the activated sludge process is shown by the B.O.D. reduction of the primary tank effluent of 94.5 per cent.

TABLE IV.—*Aeration Data, 1938*

Month	Sewage Flow M.G.D.	B.O.D. P.P.M.		B.O.D.	Suspended Solids Aeration Tank	Sludge Index	Per Cent Return Sl.	Av. Aeration Period, Hrs.	Sec. Set. Rate Gals./sq. ft./day	Av. Kw. Used Per Day	H.P./M.G.	Kw./lb. B.O.D. Rem.
		Pri. Eff.	Final	Per Cent Red.								
Jan.	0.622	158	7	96.3	676	258	32.2	9.1	496	292	26.3	0.319
Feb.	0.844	116	8	93.0	411	43	23.9	7.1	630	284	18.8	0.370
Mar.	0.784	127	8	94.0	558	76.8	25.8	7.5	593	256	18.2	0.331
April	0.886	121	7	94.3	705.6	189.6	22.8	6.8	655	273	18.3	0.327
May	0.834	124	6	95.0	659.6	251.4	24.1	8.3	624	305	21.2	0.373
June	0.922	105	6	90.5	595.0	718.0	21.9	7.6	677	322	19.4	0.425
July	0.914	107	5	95.5	693.0	505.6	22.1	7.7	672	330	20.2	0.424
Aug.	0.836	113	4	96.5	641	692	24.2	8.3	625	335	22.4	0.440
Sept.	0.790	150	8.5	94.5	605	920	25.6	8.5	596	286	20.2	0.308
Oct.	0.540	123	7	94.5	623	1030	37.2	9.8	446	254	26.3	0.480
Nov.	0.684	148	6.5	95.6	614	695	29.4	8.4	534	254	20.7	0.316
Dec.	0.702	126	8.0	93.6	570	118	28.6	8.2	543	254	20.2	0.368
Av.	0.780	126	6.7	94.5	612	391	26.5	8.1	590	287	21.0	0.371

Suspended Solids.—The average suspended solids carried during the year in the mixed liquor was 612 p.p.m., with a maximum of 706 and a minimum of 391. The average sludge index for the year was 391, with a maximum of 1030 in October, and a minimum of 43 in February. No operating difficulties were experienced during the time that the sludge index was high. In fact, clarification seemed somewhat improved under these circumstances.

The average dissolved oxygen carried in the last aerator of the batteries during the year was 4.1 p.p.m. The average power consumption during the year was 0.371 kilowatts per pound of B.O.D. removed by the aerators.

In June considerable trouble was experienced with clots of activated sludge coming to the surface of the secondary tank. Upon draining this unit, it was found that the sludge wells were full of dead leaves and grass which no doubt washed into the tank during the flood. After these were cleaned out very little further trouble in this respect was experienced.

COST

The cost of operating the Belvidere Sewage Treatment Works during the year 1938 was as follows:

Salaries and labor	$3589.30
Power @ 2.02 cents per Kw. hr.	2231.04
Truck expense	78.77
Supplies	305.63
Repairs	82.11
Total operating cost	$6286.85
Cost per M.G.	22.10
Cost per capita	0.77

The total cost of treatment during the year, including the cost of operation as shown above, and all other items of expense such as collection of revenue, bond interest and retirement, pumping costs, plant additions, and depreciation was $2.34 per capita. With the exception of operating cost, a detailed account of the rest of these items is not considered to be a part of a report of this nature.

Editorial

INDUSTRIAL WASTE SYMPOSIUM

An interesting symposium on industrial wastes was held recently by the American Chemical Society, in its meeting at Boston, September 12, 1939. Thirteen papers were presented before a joint meeting of the Industrial and Engineering Division and the Division of Water, Sewage and Sanitation. Two papers dealt with atmospheric pollution and one with legal aspects of the industrial waste problem, leaving ten concerned with liquid industrial wastes, mostly from chemical or allied industries.

The symposium was peculiarly interesting because it included discussions of waste problems by a number of men active in plant work, or consulting work for industries, and these men are usually much more reticent than their confreres in public or administrative positions. However, it is safe to say that no plant secrets were divulged. The program was so long and crowded that there was very little time for discussion, and therefore much of the advantage of the presence of industrial chemists from all over the country was lost because there was no free interchange of experience and opinion. Likewise the viewpoint of administrative authorities, national, state, or local, was not presented, although there were more questions concerning the status of national legislation (Barkley-Vinson Bill) and the legal responsibility of stream polluters, than on any technical details of the various papers.

The general aspects of water pollution were reviewed by Mr. Robert Spurr Weston, of Boston, who has had such a long career in this field. He dealt with the questions of standards of purity of streams or waterways and the degree of recovery or treatment necessary for industries using such waterways for disposal of effluents. His rational analysis of the various types of wastes, their amenability to treatment, and the means that are available for such treatment, was comprehensive and logical. (See Mr. Weston's chapter "Treatment and Disposal of Industrial Wastes" in the Federation Anniversary book "Modern Sewage Disposal.")

The legal aspects of the industrial wastes problem, as discussed by Dr. James A. Tobey, was apparently the topic of most interest to many of those present, and one discussor stated that every manufacturer in the country ought to have a copy of this paper. Of course, the courts are always the last resort in controversies over water pollution, therefore Dr. Tobey's paper should be of equal interest to sanitary authorities. For a more complete expression of his conclusions, the reader is referred to his book "Public Health Law."

Dr. H. E. Howe, the widely known and esteemed editor of *Industrial and Engineering Chemistry*, presented a fascinating and encyclopedic review of the commercial utilization of industrial wastes, including solid and gaseous by-products, as well as liquid. He emphasized the fact that in many cases what were once by-products are now normal products of operation and what we now consider necessary wastes may some day be contributing to plant income. Dr. Howe's paper was undoubtedly the most comprehensive survey that has been made of the achievements of the chemical industry in the U. S. in recovering former losses, and its publication will be awaited with interest.

Specific papers were presented on various industrial wastes, starting with Dr. C. S. Boruff, who described the million dollar waste recovery plant of the Hiram Walker Distillery at Peoria, Ill., amortized in the first two years of operation by recovery and sale of feed, syrup and special products. The feature of this process appears to be the use of centrifugals for clarification of "slop," permitting the concentration in multiple-effect evaporators to 50 per cent solids, or more, whereas screens for pre-treatment allow only 25 per cent solids in the evaporator discharge. The remaining water must be evaporated in rotary dryers, which are more expensive in operation than multiple-effect evaporators. The use of centrifugals therefore is stated to result in overall economy.

Fundamentally, however, the possibilities of profitable recovery of fermentation wastes depends upon the solids content of the original "slop," and if this is two per cent or less, recovery by evaporation will be quite expensive.

Waste problems in the paper industry were discussed by Dr. Hervey J. Skinner, consulting chemist of Boston. He reviewed the well-known story of sulfite wastes—1,000 patents, alcohol recovery accomplished in Europe but not profitable in the U. S., Howard Process at Marathon Mills but practically nowhere else, vanillin production in a few days enough to supply the country for a year, etc. The whitewater problem was also discussed and Dr. Skinner stated the losses should be less than 1.0 per cent of the product, which agrees with desirable current practice in Wisconsin.

Dr. C. R. Hoover of Wesleyan University, Middletown, Conn., and Chairman of the Water, Sewage and Sanitation Division of the Am. Chem. Soc., reviewed the work that has been done on treatment of textile wastes, particularly with respect to the details of operating plants. A large amount of data is accumulating on the treatment of wastes of this type. Dr. Hoover listed eight procedures for disposal: dilution, segregation, equalization, storage, aeration, dialysis, coagulation and biological treatment.

One of the most eagerly awaited papers was the one by Dr. Willard W. Hodge, on "Waste Problems in the Iron and Steel Industry." Dr. Hodge has been working on this problem for more than a year for the Iron and Steel Institute at Mellon Institute, and he has accumulated a large amount of information on attempts to solve the steel pickling waste problem. There seem to be almost as many patents and processes for this waste as for sulfite liquor, and the percentage recovery is at least as low as in the sulfite mills. In 1937 the pickle liquor produced in the U. S. contained 686,000 tons of copperas ($FeSO_4 \cdot 7H_2O$), whereas only 43,000 tons were recovered and used. This 16-fold rate of production, as compared to utilization, is rather staggering, and some of the widely-publicized recovery processes, such as the manufacture of insulating material, or non-tarnishing cases for silverware, do not give promise of solving the problem of disposal of surplus pickling liquor. However, Dr. Hodge is accomplishing a valuable service in acting as a clearing house for all the schemes proposed for disposal of pickle liquor, and in time he may show the way toward the alleviation of this baffling problem.

Wastes in the petroleum industry have long been studied by a Committee of the American Petroleum Institute, and the conclusions of their studies were reported by Dr. J. Bennett Hill of the Sun Oil Company. An efficient type of separating tank seems to have been developed for recovery of oil, with effluents containing only 10 to 12 p.p.m. in dry weather. The disposal of acid sludge is still a problem, also spent fullers earth.

The well-known disposal plant of the Dow Chemical Company was discussed by Ivan F. Harlow (see *This Journal,* Nov., 1938). Even more troublesome than the phenol problem has been the disposal of brine wastes, and Mr. Harlow described the method of storing such wastes and discharging them to Saginaw Bay at times of flood. The salinity contours, as determined in the waters of the Bay, were of unique interest.

"Biological Processes Used in the Treatment of Industrial Wastes" was presented by Dr. A. M. Buswell, Director of the Illinois State Water Survey. He contrasted the two major types of biological treatment—anaerobic digestion vs. aerobic filtration, and presented costs indicating that the anaerobic process would be considerably cheaper than the aerobic.

Mr. Anthony Anable, of the Dorr Company, gave the last paper, substituting for Mr. C. L. Knowles, on the viewpoint of the equipment manufacturer. He stated, among other trenchant conclusions, that only about 10 per cent of the industrial waste problems could be solved at a profit, therefore the average manufacturer should not have any illusions with respect to profits from wastes, but should be certain that he is getting the most efficient process available for his expenditure.

This closed the symposium, except for the papers by Dr. Drinker and Prof. Swain on air pollution. All papers will be published by Dr. Howe in *Industrial and Engineering Chemistry* starting in November, 1939. They should not be overlooked by those interested in the industrial waste problem.

F. W. Mohlman

Proceedings of Local Associations

PENNSYLVANIA SEWAGE WORKS ASSOCIATION

Thirteenth Annual Conference

State College, Pa., June 27–28, 1939

On the friendly and lovely campus of Pennsylvania State College, the Thirteenth Annual Conference of the Pennsylvania Sewage Works Association opened on Tuesday, June 27th, bigger and better than ever, with an address of welcome by Professor Elton D. Walker, retiring Head of the College's School of Civil Engineering and President Emeritus of the Association.

The evening before, M. W. Tatlock of Dayton had delivered a helpful paper "Laboratory Control of Sewage Treatment Plants," ending with an interesting discussion of the explosion at the Dayton plant.

Valuable papers, "Application of Sewerage Finance Methods," by Francis S. Friel; "Good Housekeeping," by L. S. Morgan, with discussions by E. E. Bankson and George P. Searight, respectively, followed Professor Walker's welcome. These were followed by the usual business session with its minutes, reports of committees, and resolutions.

Secretary-Treasurer L. D. Matter, urbane and efficient as usual, showed the healthy, active condition of the Association which now numbers 257 members. The report of the Committee on Licensing of Operators was received for study preparatory to action at the next annual conference. Report upon the Short Course School for Operators was deferred because of the grave illness of much-loved Professor Raymond "Pat" O'Donnell, Chairman, to whom the Association sent its good wishes and sympathy. New officers were elected as follows: *President,* Grant M. Olewiler of Lower Merion; *First Vice-President,* L. S. Morgan of Greensburg; *Second Vice-President,* Harry J. Krum of Allentown; *Secretary-Treasurer,* L. D. Matter of Wilkes-Barre; *Editor,* J. R. Hoffert of Camp Hill; and *Representatives to the Federation of Sewage Works Association,* C. A. Emerson and H. E. Moses.

The afternoon was devoted to a Clinic on Sewage Works, conducted by "Doctor" H. M. Freeburn, and on Industrial Wastes by Christian L. Siebert. Safe Handling of Gas, by L. L. Langford; Textile Wastes, by E. C. Manz; Activated Sludge Plant Fundamentals, by T. R. Haseltine; Milk Wastes, by S. D. Montagna; Routine Maintenance at Sewage Treatment Plants, by that sober faced humorist, Harry J. Krum; and Cannery Wastes, by H. C. Lutz, were full of real practical information and were well discussed.

The high point of the Conference was the Annual Dinner at the Nittany Lion Inn. Toastmaster H. E. "Ted" Moses, Chief Engineer of the Pennsylvania Department of Health, tried and proven and in fine fettle, introduced the distinguished guests and the officers; conferred the green Irish topper upon the novitiates of the Sludge Shovellers Society; and introduced the guest speaker, Professor Elton D. Walker. Following Professor Walker's reminiscent talk upon the advances in the art of sewage treatment, and the surprise presentation of a photo meter and a watch to the Professor by the Association and by his students in sanitary engineering, the 170 members present enjoyed two fine "talkies": "African Safari" and "News on the Air."

Wednesday morning, J. F. Hecking presented "Utilization of Sludge Gas for Power Production," which was well discussed by B. C. Thiel. It was followed by a long paper "Chemical Precipitation of Textile Wastes and Studies of pH Control," by Ralph Porges, Robert K. Horton and Herman G. Baity. This was discussed by Charles M. Nichols. Col. Wm. A. Hardenbugh presented a review "Trends in Sewage Treatment," which was discussed by Prof. Lewis V. Carpenter. This completed the formal program.

Wednesday afternoon was devoted to golf, baseball, fishing, and excursions to points of interest, jointly with the members of the convening Pennsylvania Water Works Operators' Association, which always holds its Conference in connection with that of the Sewage Works Association. With the usual fine weather, the hearty welcome of the college and the unusually large enrollment, the Conference was, indeed, the biggest and best yet.

L. D. MATTER, *Sec.-Treas.*

PACIFIC NORTHWEST SEWAGE WORKS ASSOCIATION

Fifth Annual Convention

Tacoma, Washington, May 10, 1939

The Fifth Annual Convention of the Pacific Northwest Sewage Works Association was held May 10, 1939, at the Hotel Winthrop, in Tacoma, Washington. The morning session started promptly at 9 o'clock with a registration of 93.

The first paper presented was "Pollution Studies of a Tidal Estuary." Mr. Arne Erikson, Chemical Engineer for the Washington State Pollution Commission, presented the paper and some of the findings of this study to date. Mr. Erikson illustrated his talk with charts showing the condition of the particular estuary at various conditions of the tide, with respect to the dissolved oxygen content of the water. This study, when completed, promises to be one of unusual interest in the Pacific Northwest.

Samuel Morris, Dean of Engineering at Stanford University, discussed the importance of sewage treatment and stream pollution control in water resources planning and conservation. This matter has been one of the utmost concern to the sanitary engineers of the Northwest, and, in fact, this group grew from a body of men who were actively interested in the conservation of some of these famous streams. An excellent treatise of the Scott-Darcey process of sewage treatment was given by Mr. W. J. O'Connell, Jr., Chemical Engineer of the Wallace & Tierman Company of San Francisco. Much interest was shown in Mr. O'Connell's paper and many question were asked him.

"The Principles of Good Sewer Construction" was the subject for a symposium given under the leadership of Mr. C. M. Howard of Seattle, who is the Chairman of a Committee on Sewer Pipe Joints and Infiltration. Short resumés on some of the newer type joints which have been used in several of the cities in the Pacific Northwest were given by Messrs. G. V. Robinson, Koon of Portland, and Hall of Yakima. Before adjournment Mr. Genter of Baltimore addressed the convention with a few well-chosen words, and commented upon the work and principles involved in the elutriation of sludge. The convention then adjourned to meet with the Tacoma Engineers' Club at their weekly luncheon. Their hospitality and an excellent program were enjoyed by all.

"Financing the Construction and Operation of Sewer Systems and Sewage Treatment Plants" was the subject of a paper presented by Mr. G. V. Robinson, Consulting Engineer of Portland. This timely topic formed the basis for more discussion, and Mr. Ernest Willard, Consulting Engineer, and Chairman of the Board of Rate Equalization for Portland, Oregon, discussed some of the problems confronting his Board. Mr. W. P. Hughes, Vice-President, and Chairman for the afternoon, called on the State Sanitary Engineers, Messrs. W. V. Leonard of Idaho, Roy M. Harris of Washington, and Carl E. Green of Oregon, to make a progress report on sewage treatment during the year 1938–39. The development in the Northwest in the sanitary engineering field is consistent rather than spectacular, as was evident from their remarks. Five or six new plants have been erected in each state during the last year, which, considering the scattered population, is good.

A particularly enjoyable part of the convention was a round table discussion with the following city engineers and operators participating: Messrs Barthlow of Zillah, Washington; Knittel of Lynden, Washington; Chase of Colfax, Washington; Signor of Grants Pass, Oregon; Gilman of Yakima, Washington; and Clubb of Eugene, Oregon. It is hoped that more plants will be built in this area to develop this feature of the convention. Other members, particularly Messrs. Snyder of Washington State; Koon of Portland; Eliassen of Los Angeles; Williams of Olympia; McConnell of San Francisco; Tyler of the University of Washington; and the State Sanitary Engineers, helped with this discussion.

The meeting was under the general supervision of John W. Cunningham of Portland, Oregon, President of the Association, and the local arrangements were handled by Mr. C. D. Forsbeck, City Engineer of Tacoma.

Following are the officers elected for the year 1939–40: *President,*

W. P. Hughes; *First Vice-President*, A. D. Butler; *Second Vice-President*, C. V. Signor; *Trustees*, W. V. Leonard and J. W. Cunningham; *Secretary*, Fred Merryfield.

FRED MERRYFIELD, *Secretary*

MARYLAND-DELAWARE WATER AND SEWERAGE ASSOCIATION

Thirteenth Annual Conference

Cumberland, Md., May 4–5, 1939

The Thirteenth Annual Conference of the Maryland-Delaware Water and Sewerage Association was held in the historic city of Cumberland, Maryland, on May 4th and 5th. The official registration was 107.

The Honorable Thomas W. Koon, Mayor of Cumberland, officially opened the convention with a sincere address of welcome.

On the evening of May 4th, 123 members and guests attended the annual dinner held in the Fort Cumberland Hotel. The principal speaker of the evening was "Dusty" Miller.

Following the dinner, a pleasant evening of dancing was had in the ballroom, somewhat in the fashion of the "dealers' choice," ranging from the modulated "waltz" to the "jitterburg," with special inovations.

The local entertainment committee arranged an inspection trip to the Shrine Club where the ladies of the convention demonstrated their prowess at "bridge." Following the card games, tea was served and an inspection tour made of the adjacent ground. In keeping with the true hospitality of the management of this Association, each lady attending the convention was presented with one dozen handsome cut glass goblets, the product of a Cumberland factory.

In order that more papers might be presented and longer discussions had, the usual inspection trips for the delegates were omitted at this conference.

Officers named for the ensuing year were:

President—A. M. Tawney, Fort George Meade, Md.
First Vice-President—G. E. Harrington, Washington, D. C.
Second Vice-President—J. M. Jester, Hyattsville, Md.
Secretary-Treasurer—A. W. Blohm, Maryland State Dept. of Health, Baltimore, Md.

Elected to the *Executive Committee* were:

Clarke Gardner, Salisbury, Md., 4 year term; R. J. Stewart, Edgewood, Md., 2 year term.

TECHNICAL SESSION

(President C. J. Bruce, presiding)

Mr. William J. Edwards, Superintendent of Water and Electric Lighting of Cumberland, presented an outline of the growth of Cumberland, during his 40 years tenure of office, giving special reference to the growth of its utilities and how it has kept abreast of the pace now set by the sanitary engineer and public health authorities.

The Potomac River, long a source of controversy as to ownership, later the No-Mans-Land of the Civil War, and now the repository of too much domestic and industrial waste, and with its retaliatory habit of periodic flooding, was the subject of discussion for the remainder of the morning session.

This once beautiful and virtuous river whose flow characteristics were at one time reasonably uniform is now to be the subject of a thorough housecleaning and a hydraulic harnessing to subdue its floods.

When all is said and done, and the river reverts to its virtuous state, it is possible that as in the days of old, the lone "Sentry" may even emerge from Valhalla with his doleful call "All is Quiet on the Potomac Tonight." Who knows?

The Potomac River as a subject was introduced by Mr. I. M. Glace, Consulting Engineer, Harrisburg, Pa. He discussed the past, present and future sanitary problems of the area designated as the Potomac River Conservancy District, which in effect is: those portions of the States of West Virginia, Virginia and Maryland, the Commonwealth of Pennsylvania and the District of Columbia, forming the drainage basin of the Potomac River.

A compact under which this recently created District will function was described. It appears that this compact has many of the better features of compacts in operation for other significant streams but with the burdensome and non-workable clauses omitted.

Legislation is now in progress in each of the political subdivisions involved. Similar cooperative legal requirements are necessary to permit functioning in unison. A large wall map with clear and proportionate graphic designations was used by the speaker to demonstrate the diversity of problems on the watershed, especially those relating to topography, distribution of population, industry, agriculture and sanitation. The hoped for success of the compact is predicated upon its spirit of cooperation and not upon "must" legislation.

Mr. George L. Hall, Acting Chief Engineer, Maryland State Department of Health, discussed the accomplishments in the Maryland portion of the Potomac River Basin since the necessity for the creation of a Potomac River Conservancy District was conceived a short time ago. Maryland has now passed a bill creating a commission to act in cooperation with representatives of the other political subdivisions in the District. A statistical presentation was given of the sanitary situation in Maryland with special reference to water supply and sewerage facilities and the problems relating to industrial wastes and acid drainage from active and abandoned bituminous coal mines on the North Branch of the Potomac River.

The Chief Engineer of the Washington Suburban Sanitary District, Mr. Harry R. Hall, discussed the growth of his District in the past 20 years. The District is totally on the Potomac River watershed and covers an area of approximately 100 square miles in Montgomery and Prince Georges Counties, Maryland. It is contiguous to the District of Columbia and has increased in population from 30,000 in 1918 to 100,000 at the present time. This tremendous increase in population was the result of an influx to Washington, D. C., during the period of the World War and a second influx in recent years with the surplus seeking residence in the nearby sanitary district.

As a result of these two periods of rapid growth, innumerable miles of sanitary sewers and water mains were necessary immediately. Until recently adequate water was available from nearby sources and from connections made to the system serving the District of Columbia. An extensive program is now under way for diverting water from the Patuxent River, which is just outside of the district, to immediately increase the supply.

Sanitary sewerage facilities have, heretofore, consisted primarily of the conventional collection systems with raw sewage discharged into nearby watercourses and the District of Columbia interceptors were available. The rapidity of growth, favorable topography and sound financing necessitated such a proceduce.

Coincident with the rapid growth of many new communities and the resulting increased sewage load on the numerous watercourses, intercepting sewers have been recently constructed to eliminate the numerous "sewer outlets. The new interceptors for the easternmost part of the District have been completed to a common point of collection where there will be constructed, in the near future, an activated sludge treatment plant with an immediate capacity of 7.5 M.G.D. and with provisions for expansion up to 30.0 M.G.D. This plant will be situated near the mouth of the Anacostia River, a tributary of the Potomac River. Thus the river will be relieved of another burden.

The first paper of the afternoon session was presented by Mr. Ralph E. Fuhrman, Assistant Superintendent, Sewage Treatment Plant, Washington, D. C. He discussed the various features of design and operation of the recently completed sewage treatment plant situated in the southernmost corner of the District of Columbia. All sewage is pumped to the plant from the opposite shores of the Anacostia River and the sewage passes through grit chambers metering devices and grease separating tanks enroute to the sedimentation tanks. The routing of the sewage and the sludge is typical for a modern separate sludge digestion plant employing filtration.

Stereopticon views and motion pictures, part of them in technicolor, of the entire plant, were shown to supplement the paper.

Twelve sedimentation tanks arranged in three batteries of four each are employed. Eight digestion tanks are in service in conjunction with a one 150,000 cu. ft. gas holder. Four 500 sq. ft. filters are used. The speaker presented a review of the complete analytical performance of the plant since it was placed in operation a short time ago.

Mr. Howard Chaney, of the Bureau of Chemistry of the State Department of Health of Maryland, gave a demonstration of an improvised portable device which he has developed for securing dissolved oxygen samples from streams which are normally called shallow.

A paper prepared by Mr. Carl A. Hechmer, Maintenance Engineer of the Washington Suburban Sanitary District, Hyattsville, Maryland, was read by Mr. Donnell S. Masson. It related to the numerous safety devices which are necessary to avoid the hazards in the operation of waterworks and sewerage systems. Such items as notifying consumers of shutdowns in water mains as related to potential accidents due to the explosion of hot water and steam heating plants, especially in private residences, lunch rooms and hotels were referred to. He also discussed the necessity for the venting of manholes and sewer lines before allowing workmen to enter them, especially in view of the potential danger from obnoxious and explosive gases which are the product of sewage decomposition, or of discharges from gasoline filling stations. Modern instruments for detecting such gases were discussed. An improvised fence made in the fashion of a folding gate, with arrangements for supporting lanterns at night in the interest of protecting the public from excavations; danger signs; the discontinuance of storing gasoline and kerosene in similar containers, and automobile traffic regulations in the vicinity of construction work, were discussed in sufficient detail to inform the audience of the manner in which such measures are carried out in this district and to impress them with the necessity for their use elsewhere.

Papers presented May 5 were devoted to water treatment. Immediately following the convention the executive committee voted to hold the 1940 convention in Salisbury, Maryland.

A. W. Blohm, *Secy.-Treas.*

Reviews and Abstracts

H. W. Streeter

POLLUTION AND THE POCKETBOOK

By Seth G. Hess

Municipal Sanitation, **10**, 356–358 (July, 1939)

An investigation into the economic losses traceable to pollution of the New York Harbor and adjacent waters as begun by the Interstate Sanitation Commission is reported. An attempt is made to justify, with interesting results economically, the monies spent for pollution abatement. The author states "the investigations have disclosed that monies spent on such maintenance would fully repay a community by maintaining property values, tax income and continued employment."

The investigation covered (1) losses to the fish and shellfish industries, and (2) losses to commercial and recreational areas. An accurate appraisal of total losses for an entire area is impossible and, often, the modification of the use of property makes it difficult to attribute losses to pollution or to other causes. The studies were limited to specific areas, the results from which may give some indication of the losses in the entire district. The shellfish industry still able to operate within the district does an annual business rated at $2,231,000 and represents less than 30 per cent of the area formerly devoted to this industry. Available records of shad and other fish catches within the district show material decreases in values as compared with catches made when pollution was less prevalent.

Decreases in realty values due to pollution were noted as far back as 1910. Large losses both in decline of real estate values and in loss of income due to abandonment of commercial and recreation facilities such as at Canarsie, Bergen Beach and Bergen Point are traceable directly to the pollution of the surrounding waters. Quoting the author:

"To summarize but a very small portion of the losses reported to us in the studies that we have been able to make, we find:

Loss in Capital Investments

Boardwalk Stores Corp. at Canarsie	$4,710,000
Hotels—Sunset, Oriental and Clubhouse at Canarsie	83,000
Track and roadbed to Canarsie	24,640
Four excursion boats at Canarsie	83,000
Three locomotives used at Canarsie	33,570
Ferry boat at Canarsie	3,500
Railroad coaches and equipment at Canarsie	14,375
Investment in real estate and improvements at Bergen Beach	310,000
Real estate investment at Bergen Point	1,500,000
Total	$6,762,085

The reported annual losses which follow cannot portray the full economic loss represented by unemployment and readjustments resulting from the changes brought about by pollution.

ANNUAL LOSSES

Raritan Bay shellfish	$ 500,000
Manhasset Bay	12,465
Long Island Sound shellfish	127,223
Jamaica Bay shellfish	2,826
Great South Bay shellfish	130,000
Newark and Princess Bay shellfish	357,500
Upper East River shellfish	195,000
Shellfish leases in Raritan Bay	27,000
Shad in Hudson River	89,037
Income from excursion boat at Canarsie	1,227,100
Salaries of R. R. employees at Canarsie	46,200
Ferry income at Canarsie	7,500
Income from hotels at Canarsie	343,000
R. R. fares paid at Canarsie	210,000
Loss of rental from concessions at Bergen Beach	30,000
Net concessionaire income at Bergen Beach	324,000
Salaries paid by concessionaires at Bergen Beach	100,000
Income from concessions at Bergen Point	700,000
Income from Arena and Theater at Bergen Point	150,000
Tax loss to city of Bayonne from Bergen Point	30,000
Net income of 3 hotels at Bergen Point	405,000
Losses at Classen Point Park	1,000,000
Total annual loss	$6,013,851

If these annual losses were continued for 20 years, they would represent a total of $120,277,020.

"The total losses over a period of 20 years amount to $127,039,105 or a sum sufficient to have built sewage treatment works to abate all of the pollution which caused these losses. It must be recognized, of course, that these losses represent only such investigations as could be made with limited funds and covered only 4 amusement parks, together with the reported shellfish and fish losses."

The shore line of the four amusement parks considered total about 2½ miles as compared with about 187 miles of shoreline in the City of New York alone. If the losses as reported could be applied in like manner to all of the area within the Interstate Sanitation District, the total losses would indeed be staggering.

C. T. CARNAHAN

VENTILATION OF SEWERS

BY L. B. ESCRITT

The Surveyor, **95**, 815 (June 23, 1939)

This article opens with an abstract of the ventilation experiments of the North Outfall at Los Angeles (*Sew. Wks. Jour.*, **11**, 264 (March, 1939), and a summary of the corrosion conditions in the Cairo, Egypt, sewers where heavy silt deposits in the sewer caused the detention of organic matter with the subsequent production of H_2S. Ventilation, silt removal and chemical treatment of sewage was tried without success to stop the corrosion. The successful plan consisted of rebuilding the sewer arch with brickwork pointed with tar and pitch. The author continues, drawing the following conclusions from the above investigations.

"1. H_2S is produced in sewers of low detention period when silt is able to collect. It may also be assumed that the gas is formed in the absence of silt when septic conditions can occur.

2. The disintegration due to the H_2S takes place only above the level of the sewage, *i.e.,* in the air or gas-filled portion of the sewer.

3. Prevention of cause of formation of the gas is a primary consideration.

4. When gas formation cannot be prevented, adequate ventilation is of great assistance.

5. Concrete sewers are most liable to disintegration but other sewers are not immune. Close-jointed brickwork or lined sewers are less liable to disintegration, but require pointing with a suitable material. Dense concrete has been stated to be less liable to disintegration than the weaker varieties."

Sewer ventilation has been considered advisable for:

1. Prevention of nuisance by the dilution of sewer gas.
2. Removal of explosive gas mixtures from sewers.
3. Prevention of gas collections liable to endanger men working in the sewers.
4. Prevention of corrosion.

The bellows action caused by the filling and emptying of sewers as a result of the different flow rates at various times of the day has a marked effect on ventilation. The most important ventilating agent, however, except on the calmest days, is that due to differences of barometric pressure at the various parts of the sewage system, in other words, wind action. The air flow in the sewers will be in the same direction as the wind, and will often be more marked than the wind at the surface.

Advantage should be taken of this fact in the design of sewerage system ventilating arrangements. The barometric pressure differences will normally be very small but a minute difference of pressure will bring about a reasonable flow in a pipe as shown by the following simplified formula:

$$Q = 39d^2 \sqrt{\frac{Pd}{L}},$$

where:

$Q =$ cubic ft. per minute of air (at initial pressure),
$d =$ diameter of pipe in inches,
$P =$ pressure difference in inches of water,
$L =$ length of pipe in feet.

In smaller sewers the greater part of the friction loss will be due to the surfaces of the sewers themselves while in larger sewers, running partly full, the greater part of the friction losses will occur at the inlets and outlets, the small openings in manhole covers and the restricted diameters of ventilating shafts which are often not much larger for big sewers than for small ones.

C. T. CARNAHAN

RAPID BIOLOGIC FILTERS FOR A SEWAGE PLANT

BY HARRY A. JENKS

Eng. News-Record, **122,** 839 (June 22, 1939)

A new sewage treatment plant has been completed at Petaluma, California, to treat the domestic sewage from a population of 12,000 and industrial wastes with a population equivalent of 20,000. The average flow to the plant is 0.7 m.g.d. with a peak flow of 1.25 m.g.d. Industrial wastes include discharges from two milk products plants, a molasses factory and a silk mill. The plant includes primary settling, two-stage rapid biologic filters, secondary settling and separate sludge digestion facilities.

The sewage is collected by an interceptor which ends at a pumping station. Here the sewage passes through a comminutor before being lifted 12 ft. by automatically controlled pumps for gravity discharge into a river crossing leading to the plant. At the plant the sewage is again screened through an automatic bar screen and is lifted 14 ft. for gravity flow through the treatment units.

The raw sewage as it enters the primary clarifier is immediately diluted with the effluent from the primary bio-filter. The diluted sewage then passes through the primary recirculation pump for discharge through the rotary distributor of the primary coarse rock bio-filter bed. A portion of the primary clarifier unit equivalent to the raw sewage flow is automatically diverted to the secondary recirculation pump for dosage onto the secondary bio-filter. The effluent of the primary filter is returned to the influent of the primary clarifier to dilute the incoming raw sewage. Partly oxidized effluent from the first stage combines in the secondary recirculation pump with effluent from the detention-settling-tank of the second stage for discharge to the fine rock bed of the secondary bio-filter, the effluent of which flows to the secondary (final) settling tank. The plant effluent is diverted from the secondary settling tank effluent over a control sill in an amount corresponding to the volume of flow through the treatment works.

Each of the bio-filter beds is of 75-ft. diameter inscribed within octagonal enclosing walls and contains filter material to a depth of three feet. The bottoms consist of concrete sleepers poured in place on three foot centers, extending across the floor slab and providing support for a grillage of 2×4 inch irrigation grade redwood lumber. An initial layer of coarse rock was hand placed over this grillage to prevent penetration of the filtering material into the underdrains. The primary bio-filter is designed to accomplish chiefly the biochemical flocculation of colloidal material and the initial reduction of the biochemical oxygen demand and the filter material is crushed rock from 1½ to 2½ inches in size to allow for ample ventilation. The secondary bio-filter bed is of crushed rock of 1 to 1½ in. size to provide as much surface area as practical for further biochemical oxidation of the relatively weak influent and for the production of nitrates in the final effluent.

Three recirculating pumps are provided, each with a capacity of 2100 g.p.m. against a head of 8.5 ft. and a pump efficiency of 82 per cent. The third pump is so connected that it can be used to cooperate with either of the other two or serve as a standby pump for either the first or second stage recirculation and is driven by a variable speed motor. Each stage of recirculation requires a 7½-hp. motor and affords a recirculation ratio of 3 : 1 based on the design flow of 1 m.g.d. Thus the power required for the biologic treatment of this sewage having a B.O.D. of approximately 300 p.p.m. is 15 hp. per million gallons.

Since September, 1938, when the plant went into operation, no clogging of either filter bed has occurred, although there has been incipient ponding of the secondary bed at infrequent intervals. This is entirely a surface condition, readily eliminated by raking the bed to a depth of 3 or 4 in. *Psychoda* flies are absent as long as the filters are in operation. Within a few days after a filter is shut down, the flies appear in the usual numbers characteristic of an ordinary trickling filter, but disappear again within a couple of days after operation is resumed.

R. S. SMITH

AERODYNAMICS OF TRICKLING FILTERS

BY EDGAR L. PIRET, CHARLES A. MANN, AND H. ORIN HALVORSON

Ind. & Eng. Chem., 31, 706–712 (June, 1939)

During the experimental work leading to the development of the high-capacity trickling filter by Halvorson it was found that the flow of air was important to its operation. The flow of air was found to be upward or downward depending upon the relative temperatures of the water and the outside air. In summer when the water was colder than the air, the flow was downward through the filter bed, reversing in winter when the air was colder than the water. Due to uncontrollable conditions affecting the outdoor experimental plant, quantitative measurements could not be made.

In this investigation an attempt was made to develop a more fundamental understanding of the mechanism of the flow of air by studying the influences of air and sewage temperatures, humidification and the dragging effect of the water in a clean filter. A cylindrical steel filter 2.5 ft. in diameter filled with 6 feet of 1¾ in. unbroken gravel was erected in a laboratory room where the air temperature could be kept reasonably constant. Water temperatures were controlled by means of an insulated, thermostat-controlled-tempering tank and the feed water was applied to the filter by a rotary distributor and a motor-driven gear pump. The bottom of the filter was enclosed and the air flow was measured by a hot wire anemometer in a contracting tube. Effluent was removed through a trapped pipe to prevent air from escaping except past the hot wire anemometer. Clean water was used instead of sewage in order to eliminate the variables that might be introduced by changes in flora in the filter.

In one set of experiments the filter was dosed continuously at various rates from 1 to 20 million gallons per acre per day and measurements of air flow taken at various water temperatures from 60° F. to 75° F. and room temperature from 72° to 82° F. It was found that the flow of air was a straight line function of the difference between the temperatures of the water and the outside air. The dragging effect of the water was found to be negligible.

As most filters are operated at low average rates with intermittent dosage, a run was made dosing the filter at 26 m.g.a.d. for 2 minutes and then resting for 23 minutes, giving an average rate of 2.1 m.g.a.d. Previous to starting this run the filter was brought to room temperature by continuous dosing for 12 hours with water at a temperature of 75° F. During the experimental run the temperature of the feed water was 61° F. During the short dosing periods there were marked pulsations in the rate of air flow. It is stated that these pulsations are not due to the dragging effect of the water on the air in the filter, and it is explained that during intermittent operation of a filter these rapid pulsating changes in air flow take place during the dosing period if the temperature of the filter is not the same as that of the water being distributed on it.

The authors summarize their findings as follows:

> 1. The flow of air at equilibrium and with continuous water distribution is a straight-line function of the difference between the temperature of the outside air and the temperature of the water.
>
> (*a*) This relation is not appreciably affected by changes in water dosage rates between the limits of 1 and 20 m.g.a.d.
> (*b*) The effect of humidification of the air is relatively slight except when the temperatures of the water and the air are approximately the same. It will tend to cause a slight upward draft under those conditions.
>
> 2. The dragging effect of the descending water is negligible.
> 3. During intermittent distribution pulsations in air flow will take place as a result of the increased heat transfer during the dosing period. For a given amount of water being dosed on a filter, the data indicate that intermittent dosage will not bring as much air through the filter as continuous dosage. The maximum air flows obtained during the pulsations in intermittent dosage are less than the equilibrium flow set up by continuous distribution.
> 4. The filter medium, during continuous dosage at high rates, comes to the temperature of the water and not to that of the air flowing in natural draft.

R. S. Smith

DETERMINATION OF DISSOLVED OXYGEN IN AQUEOUS SOLUTIONS

By G. A. Perley

Ind. & Eng. Chem., Analytical Edition, **11,** 240–243 (1939)

An electrometric method for the titration of iodine liberated by the Winkler method for the determination of oxygen is described and recommended as reliable where small quantities of dissolved oxygen are involved.

Three samples of water are collected in series in bottles equipped with rubber stoppers and inlet and outlet tubes. Slightly oversize sampling bottles to collect two 250 ml. samples and one 500 ml. sample are used and the system is flushed out 7 times the total volume of the bottles before the sampling is stopped. The reagents used include .01 N sodium thiosulfate solution, .01 N potassium biniodate solution, manganese chloride solution, alkaline-iodide reagent and concentrated H_2SO_4 diluted with an equal volume of water.

The 500 ml. sample and one of the 250 ml. samples are treated as in the normal Winkler procedure until the iodine has been liberated by acidification with 2 ml. of the sulfuric acid. Then 250 ml. of sample from the 250 ml. bottle is measured out and 250 ml. of untreated water from the other 250 ml. bottle is added to this. Exactly 0.5 ml. of .01 N potassium biniodate solution is then added. The addition of the standard biniodate serves as a check particularly when small traces of oxygen are present. The sample is titrated electrometrically with .01 N sodium thiosulfate using a certified burette with a special tip to give not over 0.02 ml. per drop. Exactly 500 ml. of sample from the 500 ml. bottle are measured out and titrated similarly. The oxygen content for a 250 ml. sample is determined by the difference between the 500 ml. and the 250 ml. sample.

A platinum sheet 1 × 1 cm. with a suitable lead is used as the indicator electrode, and a saturated calomel-saturated potassium chloride system is used as a reference electrode. The two electrodes are mounted in an 800 ml. beaker provided with a mechanical stirrer which is operated during the entire titration. A portable potentiometer with a range of 0 to 1100 millivolts is used to obtain the e.m.f. per ml. of thiosulfate relationship. As the significant abrupt e.m.f. change is easily detected, a complete titration is not necessary. The standard thiosulfate may be added rapidly until the e.m.f. is about 0.3100 volt, and the titration continued drop by drop until the end point is reached. The end point occurs between 0.290 and 0.260 volt, depending upon the nature of the solution, the pH of the solution and the concentration of the iodide present. In any case, at the exact end point one drop of 0.01 N thiosulfate solution results in an abrupt drop of over 30 millivolts. The author was able to detect .0064 p.p.m. of oxygen in a 250 ml. sample by this method. The influence of dissolved oxygen in the reagents, small ionic variations of foreign substances, secondary reactions, loss of dissolved oxygen by displacement, possible contamination of the sample by air when the reagents are added and temperature variations are minimized by the procedure presented.

C. C. RUCHHOFT

USES AND ABUSES OF THE BIOCHEMICAL OXYGEN DEMAND

By M. STARR NICHOLS

Am. Jour. of Public Health, **29**, 901–906 (Aug. 1939)

"The B.O.D. determination has become the most widely used test in modern sanitary control of all liquid wastes. Like most tests which have been devised to measure the progress of natural biologic phenomena, it has its uses and it has its limitations."

Experience has shown that the B.O.D. of domestic sewages seems to offer the best single test of their strength. Industrial wastes, however, may not be so well adapted to the B.O.D. test due to their unfavorable composition. (1) Some organic wastes may be so greatly lacking in nitrogen and phosphorus compounds as to give extremely low values of the B.O.D. under standard procedures. (2) Certain chemical or mineral constituents in the wastes may destroy bacterial life and render the B.O.D. test impossible. (3) Industrial wastes high in nitrogenous materials but otherwise suitable for the B.O.D. test will give low results if the incubation period is short as the second or nitrogenous stage of the B.O.D. is not measured.

The author reviews briefly some of the experimental work on the mechanics of the B.O.D. determination and comments at length on the effect of phosphorus and nitrogen on the B.O.D. Test. A supplemented bicarbonate dilution water containing these elements is recommended for use on those organic wastes in which phosphorus and nitrogen are low or absent. The composition of this dilution water is given as follows:

Ammonium sulfate	2.5 p.p.m.
Tricalcium phosphate (anhy.)	0.01 p.p.m.
Magnesium sulfate crystals	0.01 p.p.m.
Dihydrogen potassium phosphate	0.1 p.p.m.
Sodium bicarbonate	300. p.p.m.

Made up with distilled water free of copper.

Experiments show that the addition of the phosphorus and nitrogen supplements do not cause in themselves a usage of oxygen. There is practically no production of nitrate or nitrite within the usual 5-day incubation period and not sufficient amounts up to 30 days to influence the B.O.D. result greatly.

Results on various wastes showing the increased demands obtained with this dilution water are shown in the table below:

TABLE I

Type of Waste	B.O.D. Using Plain Bicarbonate Dilu. Water, Std. Methods, 8th Ed., P.P.M.	B.O.D. Using Same Water Plus Mineral Supplement, P.P.M.	Per Cent Increase in B.O.D. Values Using Supplemented Water
Glucose, 1000 p.p.m.	60	470	670
Sulfite waste effluent	550	4,325	685
Domestic sewage	217	221	2
Whitewater, paper waste	25	62	148
Bleach water, paper waste	30	148	390
Black liquor, pulp waste	480	1,450	200
Pea canning waste	940	893	−5
Beet canning effluent	460	1,570	240
Settled sewage *	135	140	4

* Results by Dr. W. D. Hatfield of Decatur, Ill.

The above table shows that those wastes containing adequate natural amounts of phosphorus and nitrogen give comparable B.O.D. values with both dilution waters while wastes low in phosphorus and nitrogen give much higher B.O.D. values when the supplemented dilution water is used. This may be explained by the absence of bacterial growth and multiplication in the usual bicarbonate dilution water.

The use of this supplemented dilution water probably gives a better picture of the actual effect of low phosphorus-nitrogen carbonaceous wastes upon stream waters. This is because the phosphorus and nitrogen in the dilution water are comparable to the normal amounts of these elements as found in natural stream waters and thus more nearly approach the conditions which would result from the mixing of the wastes with stream waters.

Care should be exercised at all times in interpreting the B.O.D. test so as to properly weigh all factors involved and to evaluate the usefulness of the results obtained. If the B.O.D. test is to be used for wastes other than sewage, for which it was originally devised, attention must be given to all factors affecting bacterial growth in the test bottle. "Not only must toxic and inhibitory substances be excluded from the test bottle, but adequate non-oxygen-using minerals of cell metabolism be provided, either by the waste or in the dilution water; otherwise the test falls short of its 'biochemical' name."

C. T. CARNAHAN

SOME CHEMICAL AND BACTERIOLOGICAL PROPERTIES OF TRADE WASTES CONTAINING CHROMIUM

By H. E. Monk

TREATMENT OF CHROMIUM PLATING WASTES

By J. H. Spencer

Sewage Purification, **1**, 364, 356 (Aug., 1939)

The first paper deals with laboratory investigations on chromate containing wastes from chromium plating and anodizing processes. In the former, the vat liquors are almost never discharged and the chief waste consists of "swill" water from washing. This waste is relatively dilute, a typical analysis showing 13 parts per 100,000 of chromate as CrO_3. In the chromic acid process of anodizing, in addition to the "swill" water, the highly acid vat liquors, containing perhaps 46,000 p.p.m. chromate as CrO_3, are also occasionally wasted.

Chromium plating wastes have a precipitating action upon sewage, the chief effect being a colloid flocculation, with nitrogenous matter showing a higher than proportionate removal.

In order to estimate the chromate strength which might be allowed in sewage without harm to biological purification processes, various concentrations were tested upon suspensions of *B. Aerogenes*. In a series of tests using anodizing vat liquor waste, neutralized with lime water, results were obtained as tabulated below.

Neutralized Anodizing Waste: Action on *B. Aerogenes*

Per cent survivors in	CrO_3 Concentration per 100,000			
	50	25	5	1
½ hour	39	47	66	91
1 hour	25	27	64	91
2 hours	22	24	54	84
4 hours	0	6	1	6
24 hours	0	0	0	0

Based on these investigations, the author concludes that 5 parts of CrO_3 per 100,000 may be considered a safe figure for chromate concentration in sewage arriving at the treatment works.

In a few experiments conducted on yearling perch, it was found that 25 parts CrO_3 per 100,000 killed in about 3½ hours, but that at 10 parts per 100,000 the fish were apparently unaffected at the end of 18 hours.

The second paper relates of the difficulties at a small municipal sewage treatment works caused by chromium plating wastes and the remedial steps taken. The treatment plant, comprised of a settling tank and filter beds, had operated satisfactorily for many years prior to 1933, when a local factory started chromium plating. With chromium concentrations ranging from 0.35 to 6.76 parts Cr per 100,000 in the raw sewage, biological action in the filter beds was entirely stopped and no life could be detected by microscopic examination of the filter medium.

The plating factory waste consisted of drainage from the tanks in which plated articles were washed in sodium carbonate solution and in clean water. Essentially the waste was an alkaline solution of sodium chromate with an average content of 76.4 parts Cr per 100,000.

In order to remove the chromium, a plant has been built to treat the waste prior to its discharge from the factory. The treatment consists of the addition of barium chloride to precipitate the chromium as barium chromate, the pH being maintained at 7.5 or more to insure complete precipitation. In "semi-large scale" preliminary tests, the process resulted in a decrease of chromium content of the waste from 75.8 to 0.1 parts Cr per 100,000. In the tests, an excess of 15 to 40 parts of Ba per 100,000 was found necessary to insure complete precipitation of the chromate. As barium salts are somewhat poisonous, it was decided to remove this excess barium by precipitation with sodium carbonate.

In the trade waste plant as constructed, treatment is obtained by batch process in two hopper-bottom steel tanks, lead lined for corrosion resistance against possible acid discharges, each of sufficient size to hold a day's maximum flow. To the accumulated waste, the proper quantities of barium chloride and sodium carbonate are added, mixed with compressed air, and the tank contents allowed to settle for at least 1 hour. Additional sodium carbonate is then added to precipitate the excess barium and the tank contents are again agitated with air and allowed to settle overnight. After withdrawal of the sludge, the treated liquor is discharged to the sewer over a period of 4 to 6 hours.

V. G. MacKenzie

OXALIC ACID FROM SULFITE WASTE LIQUOR

By T. J. Skewes and H. K. Benson

Ind. & Eng. Chem., 31, 1133–35 (Sept., 1939)

Oxalic acid is frequently found as a minor product in the decomposition of complex organic substances by the application of heat alone or by suitable chemical treatment. This acid may appear as a major product under certain conditions such as the fusion of sawdust with sodium and potassium hydroxides at 220° C. or by the oxidation of wood, in the form of sawdust or wood flour, with nitric acid. Considerable work has been done on the treatment of cellulosic materials with nitric acid for the production of oxalic acid, and a small amount of work has been done on the nitric acid oxidation of sulfite waste liquor and isolated lignin.

A patent was granted in 1917 covering a process for evaporating sulfite waste liquor with concentrated nitric acid and treating the residue to recover the oxalic acid.

Heuser, Roesch and Gunkel recovered a 20 per cent yield of oxalic acid by treating isolated lignin with concentrated nitric acid.

"This paper deals with the nitric acid oxidation of the following sulfite waste liquor products for the formation of oxalic acid":

1. Sulfite waste liquor before concentrating by evaporation. Results of experiments described by the authors gave no yield.
2. Solids obtained by highly concentrating the liquor. The methods used by the authors gave yields of 24.5 to 28.4 per cent based upon weight.
3. "Raylig" a commercially concentrated product which gave yields of oxalic acid (dihydrate) of about 28 per cent under the treatment used.
4. Precipitated calcium lignosulfonate which was prepared from sulfite liquor with lime and the evaporated residue when treated gave oxalic acid yields of about 21 per cent.

The experiments were repeated using dilute nitric acid. The results of the tests are shown in the table below taken from the article:

Results of Treatment with Dilute and Concentrated Nitric Acids on Solids

Material	Weight Grms.	Nitric Acid Ml.	Max. Temp. °C.	Oxalic Acid Yield [a] Per Cent
Concentrated Nitric Acid (70 Per Cent)				
Evap. total solids	5	20	90	28.6
Calcium lignosulfonate [b]	5	20	90	21.0
Raylig [c]	5	20	90	27.3
Dilute Nitric Acid (10 Per Cent)				
Evap. total solids	5	40	—	8.02
Calcium lignosulfonate [b]	5	40	—	0.45
Raylig [c]	5	40	—	6.00

[a] Dihydrate.
[b] Dried at 105° C.
[c] Containing 6.87 per cent moisture.

The use of vanadium pentoxide as a catalyst did not affect the yield of oxalic acid appreciably. The methods and materials used in making the experiments are discussed at length by the authors.

C. T. Carnahan

FINAL REPORT ON INCINERATOR ACCEPTANCE TESTS MINNEAPOLIS–ST. PAUL SANITARY DISTRICT

By Geo. J. Schroepfer, *Chief Engineer and Superintendent*

(Mimeographed Report)

April 24, 1939

Description of Equipment.—The sludge incineration equipment at the Minneapolis-St. Paul sewage treatment plant consists of three Nichols-Herreshoff incinerators, 22 ft. 3 in. O.D. by 8 hearths high. In these units, the sludge filter cake is fed in at the top and is dried and burned while being moved downward from hearth to hearth by rabble-arms and teeth suspended from a central rotating shaft. From the lowest hearth the ash is discharged into a pit under the incinerators from which it is removed by hydraulic sluicing and is pumped to a lagoon. The principal furnace auxiliaries consist of a fan for furnishing cooling air to the center shaft and rabble arms, a combustion air fan, an exhaust gas fan, a combustion air pre-heater utilizing heat from the exhaust gases, and a dust settling flue for collection of light solid materials from the stack gases. Fuel oil burners are located on several hearths to supply auxiliary heat if needed during the incineration process.

Requirements of the Specifications.—The incinerator specifications, under which the equipment was furnished, called for a plant capable of reducing sludge containing 180 tons of dry solids per day to a clean ash without nuisance. The material to be incinerated was to be that derived by vacuum filtration of sewage sludge produced by either plain sedimentation or chemical precipitation, followed by treatment with magnetite filters. The incinerators were specified to be able to handle a variable load, with sludge filter cake also varying within wide limits as follows:

Tons of dry solids per day	60	to	180
Per cent moisture	60	to	75
Per cent combustibles	30	to	70
B.T.U. per pound of combustible	9,000	to	11,000

Bidders were required to submit guaranteed curves and data on power, labor, fuel oil and other operating and maintenance costs and to post a bond to assure that the actual costs obtained would not exceed the guarantee.

Preliminary Operating Tests.—The contractor was required to place the incinerators and appurtenances in regular operation for at least 30 days, during which period he should make any changes found necessary to meet the contract requirements. During the preliminary test period, the equipment was operated a total of 3864.75 incinerator-hours. A total of 23,822.3 tons of filter cake, 65.4 per cent average moisture content and 52 per cent combustibles, was burned.

The main difficulty encountered was the production of damagingly high furnace temperatures when operating at loads approaching design capacity, the principal reason for which seemed to be the low moisture content and high heat value of the sludge filter cake. Attempts to solve this difficulty by insulation of the rabble arms and central shaft and by spraying water on the sludge on the top two incinerator hearths were not satisfactory. The solution of the problem was accomplished by the installation of by-pass ducts and dampers to allow partial by-passing of the exhaust furnace gases around the preheater and to allow the partial or complete use of unheated furnace-room air for combustion. Furnace temperatures are controlled by the adjustment of the dampers.

Minor difficulties were encountered from a clinging deposit of fly-ash in the preheaters and on the hot-gas fan blades. Provision for access to the units for cleaning was necessitated.

The Ninety-Day Test.—After a preliminary operating period of about 5 months, a ninety-day acceptance test was run, during which period all sludge cake produced was incinerated and accurate records of all items of operation were kept to determine whether the incinerators met the guarantees. The principal test results were as follows:

Average hours of operation (each unit)	1,397.22
Total tons filter cake incinerated	28,242.8
Average moisture content of filter cake, per cent	64.5
Total tons dry solids incinerated	10,017.0
Average tons dry solids incinerated per unit per hour of operation	2.39
Average combustible solids, per cent	57.9
Fuel oil used for incineration, gal.	3,293.0
Electric power, K.W.H.	163,315.0
Man-hours, skilled labor	273.25
Man-hours, semi-skilled labor	44.0
Man-hours, unskilled labor	2,019.58

The total operating and maintenance costs during the ninety-day test period, including supplies and repairs, amounted to $0.455 per ton dry solids incinerated. For the actual conditions encountered, the cost guaranteed by the contractor amounted to $0.707 per ton.

Upon completion of the final acceptance tests, it was concluded that the equipment had fulfilled the requirements of the specifications and of the contractor's guarantee.

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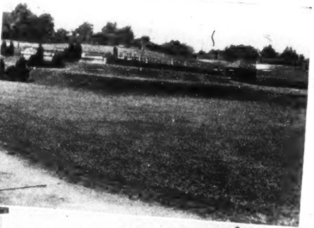

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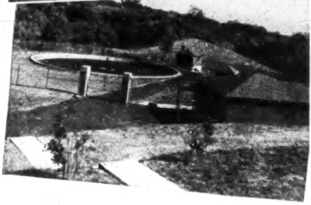

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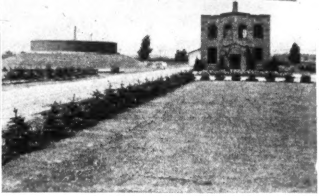

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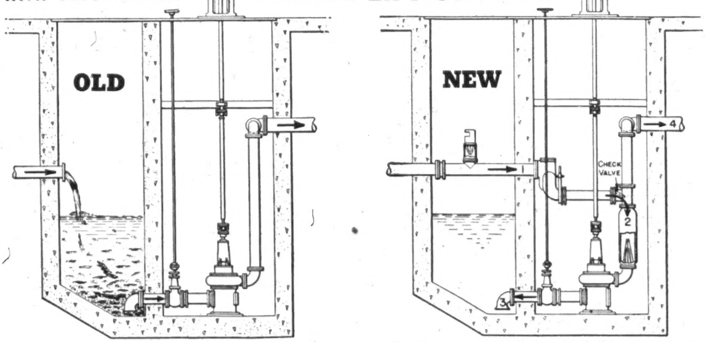

NON-CLOG (left)—Sewage flows directly into basin. Pump must handle all coarse matter, such as rags, sticks, rubbers, etc., which frequently clog pump.

FLUSH-KLEEN (right)—Sewage flows through pump to basin, as indicated by arrows 1, 2 and 3. Coarse matter is intercepted by Flush-Kleen strainer and retained in strainer chamber in discharge line of the pump at arrow 2. WATER ONLY passes through the chamber and into the basin. When water in the basin reaches a predetermined level, the pump starts and pumps the water from the basin into the sewer at arrow 4. The starting of the pump reverses the flow at arrows 3 and 2, and the check valve in the inlet closes to prevent sewage backing up into the inlet. As water from the basin is pumped through the strainer chamber, the coarse matter that has accumulated there is flushed out through the discharge line into the sewer at arrow 4.

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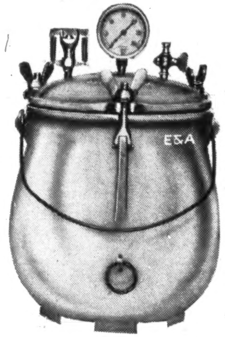

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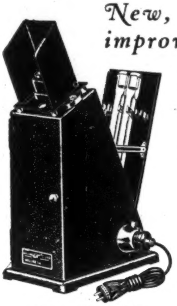

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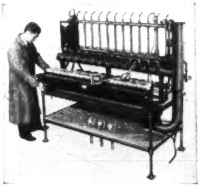

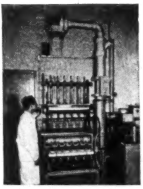

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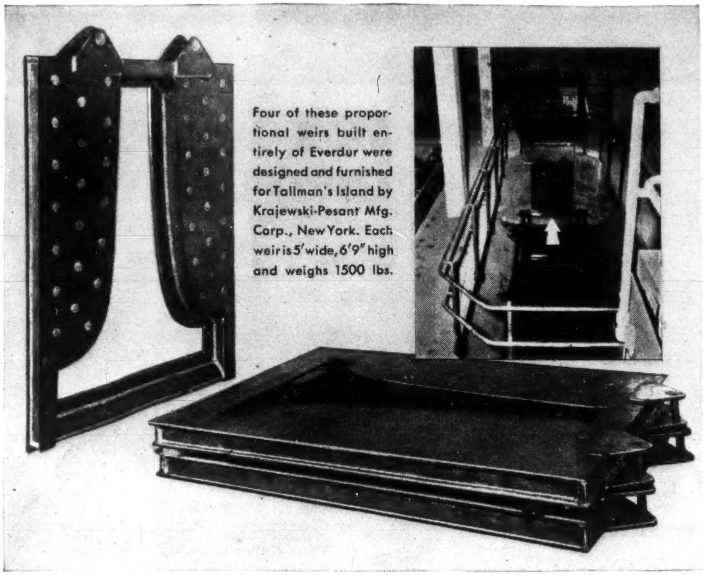

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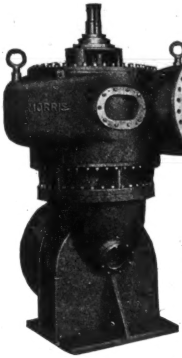

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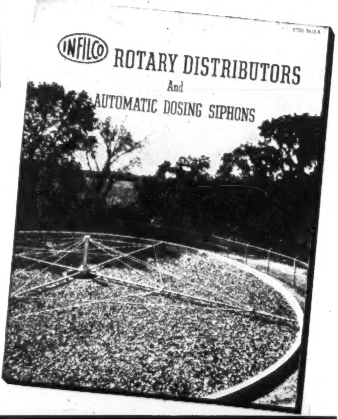

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